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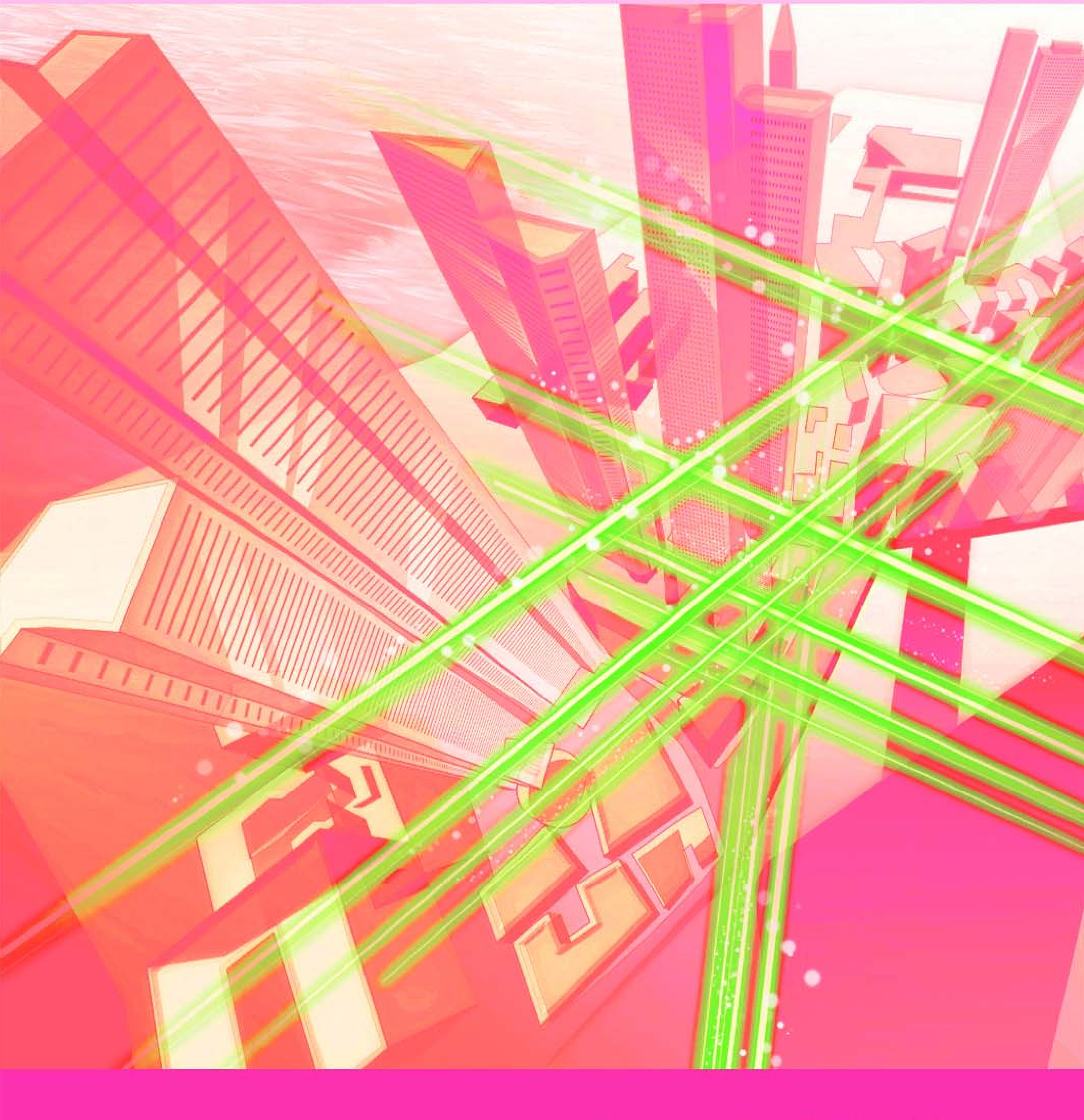

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Understanding and Shaping the Athlete's Brain —NTT Sports Brain Science Project—

Makio Kashino

Abstract

In sports, a variety of brain functions hold the key to winning, such as grasping current conditions, strategizing against one's opponent, and making instantaneous decisions under pressure. Most of these functions, however, are *implicit* brain functions that the athlete is not even aware of. The NTT Sports Brain Science project was established in January 2017 to conduct research with the aim of understanding superior implicit brain functions in top athletes, identifying the factors in winning, and improving the performance of athletes based on research findings.

Keywords: sports brain science, implicit brain functions, body-mind reading

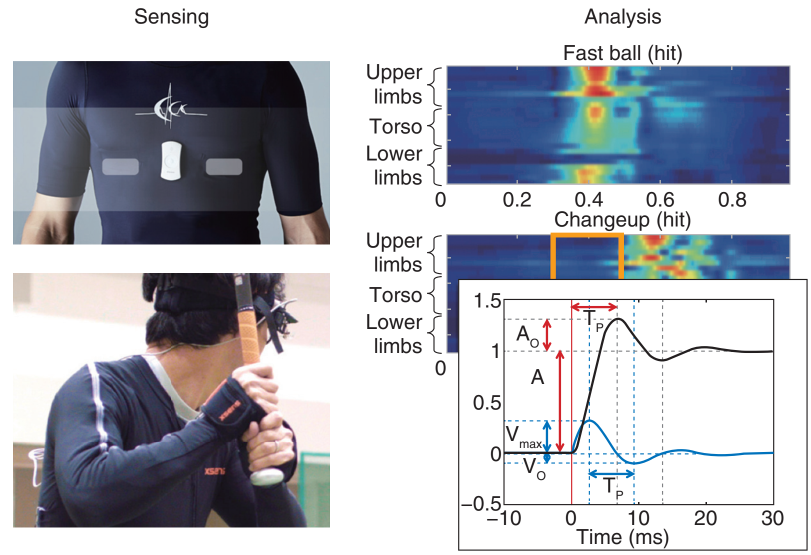
1. Importance of the brain in sports

What are the necessary conditions for becoming an outstanding athlete? It goes without saying that physical abilities are important such as a resilient body excelling in muscular strength and cardiopulmonary function and an appropriate form that can effectively produce power and minimize the risk of injury. However, to reach even higher levels as an athlete, physical abilities by themselves are not sufficient. There is also a need for other faculties such as the ability to grasp match conditions, develop a strategy and make instantaneous decisions, the ability to predict your opponent's next move based on current behavior and take preemptive action, the ability to deceive and manipulate your opponent, the ability to quickly and flexibly adjust one's actions even during complex moves, and the ability to amply demonstrate one's strengths while under intense pressure during a big match. None of these abilities can be achieved without advanced information processing in the brain. In general, top athletes are especially proficient in such brain functions.

Research in conventional sports science and associated training techniques has led to an accumulation of substantial results from a physical point of view. However, brain functions in relation to sports are still largely unexplored even from a global perspective. Against this background, NTT launched its Sports Brain Science project (SBS) in January 2017 as an interdisciplinary research organization [1]. The purpose of SBS is to understand the brain functions that support superior performance in top athletes and to actually improve the performance of athletes based on those scientific findings. Now, with about one year behind us, we are off to a good start, having gained the cooperation of top-level athletes and teams centered on baseball and softball. Here, I would like to introduce the basic concepts and research policy of SBS.

2. Deciphering implicit brain functions

In sports where athletes play against an opponent, for example, baseball and martial arts, the time allowed for grasping ever-changing conditions, making



(a) Measurement of heart rate, body motion, and eye movements using wearable sensors

(b) Feature analysis of body movements and eye movements

Fig. 1. Deciphering and adjusting implicit brain functions.

decisions and predictions, and adjusting movements is exceedingly short, on the order of split seconds. For the athlete, this is too short a time to recognize or consciously control something that occurs in the brain. Out of necessity, important brain functions in sports with an opponent are for the most part unconscious activities. From the athlete's perspective, the feeling is that *the body reacts on its own*.

These brain functions, however, are different from spinal cord reflexes and other simple reactions common to everyone. Rather, they are extremely advanced functions the knowledge of which would not be possible without the results of a massive amount of learning about the behavior of opponents and physical objects such as balls and the way the body moves in response to that behavior. Such brain information processing affects complex actions while being unconscious to the athlete, and for this reason, we refer to different instances of such processing as implicit brain functions. We have been involved in the basic (i.e., not directly sports-related) research of implicit brain functions for many years [2]. The first objective of SBS is to clarify how the various elements of these implicit brain functions related to sports performance differ between superior athletes and regular athletes.

However, implicit brain functions by their very nature prevent an athlete from being aware of them, so asking a top athlete about them is no help in arriving at the truth. It is rare for a person excelling at a certain skill to be able to accurately put into words how he or she does it. Even if the skill can be verbally described, it is not uncommon for those words to describe not what actually occurs but rather to fit the results observed. This is thought to be one of the factors behind the difficulty of coaching a specific skill. A great player does not necessarily make a great coach.

With this being the case, SBS has been using *body-mind reading* technology developed at the NTT laboratories with the aim of deciphering the implicit brain functions of athletes (**Fig. 1**). The first step in this technology is to measure the movement of various parts of the athlete's body in action and various biometric signals. Of great importance here is that such measurements be made under conditions as close as possible to those of a real match without impeding the athlete's inherent performance. Here, we use multiple video cameras and wearable inertial sensors to record body movements and quantify them. We also use wearable sensors to measure biometric signals such as brain waves, cardiac potential and heart rate, respiration, and myoelectric potential. Additionally, we use camera goggles to track eyeball movements.

The second step is to use the data obtained from these measurements to extract essential information

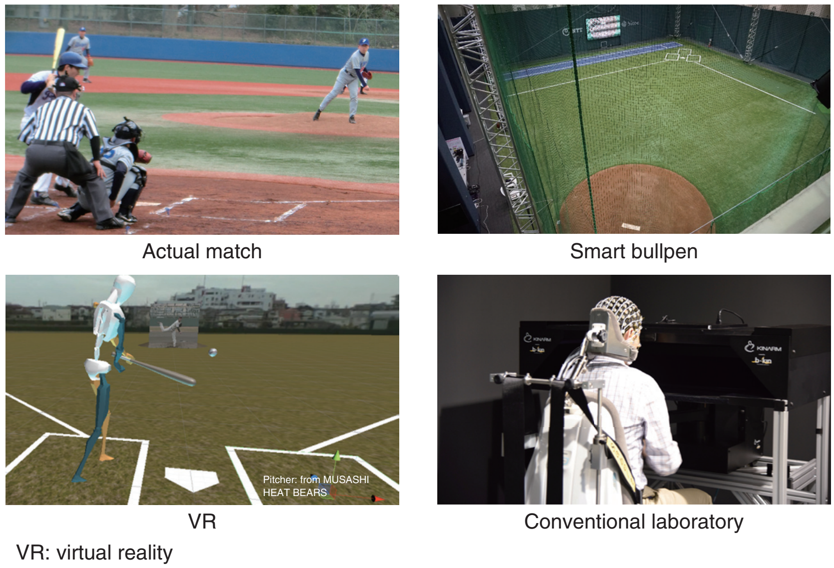


Fig. 2.   Four types of experimental environments.

on the physical behavior and brain information processing of athletes. Here, to obtain information on brain information processing, the brain activity does not necessarily have to be measured. For example, eyeball activity (direction of line of sight, fine eye movements called microsaccades, changes in pupil diameter, etc.) reflects and changes the internal brain conditions (surprise at something unexpected, direction and extent of attention, information processing load, etc.). That is to say, if eyeball activity can be analyzed, it should be possible to infer to some extent internal brain conditions at that time [3]. Similarly, changes in heart rate and respiration, for example, can provide information related to underlying brain activity more so than the movement of certain parts of the body.

To carry out such analysis, we are applying various artificial intelligence related technologies from NTT's corevo™ initiative including image processing, biometric signal processing, and machine learning. In all, these analysis technologies constitute body-mind reading, which is becoming a powerful tool in the hands of SBS.

Appropriate experimental environments are needed in order to conduct experiments that can capture the essence of sports. In SBS, we divide experimental environments into four main types (**Fig. 2**). The first is an actual match. The stress that accompanies the need to perform cannot be felt outside of an actual match. In the case of baseball games, we attach a wearable sensor ("hitoe") under the athlete's uniform to capture heart rate, acceleration, and other data, and we analyze how psychological factors can influence performance. However, the fact that an actual match is literally real also means that many factors including accidental occurrences and things that cannot be identified will be intertwined in a complex manner. As a result, the experimenter does not have control over everything in such an experiment.

With this in mind, the second type of experimental environment is the smart bullpen that we created to extract at least a portion of the true nature of sports while enabling a controlled experiment. Details are provided in another of the Feature Articles [4] in this issue, but in brief, the smart bullpen is an experimental facility equipped with multiple cameras and various measurement devices in a space such as an indoor baseball practice area. A key feature of this facility is the ability to analyze in detail the mutual interaction among multiple athletes, as in the battle between a pitcher and batter in baseball and softball. The essence of competitive sports lies in the mutual interaction between players. Simply analyzing pitching or batting will not lead to an understanding of what it takes to win. The smart bullpen enables the physical movements and biometric signals of both the pitcher and batter to be measured synchronously under competitive conditions while also enabling the behavior of the ball (velocity, spin, trajectory, etc.) to be simultaneously recorded by specialized radar. An example of an experiment using this smart bullpen is described in another Feature Article [5] in this issue.

The third type of experimental environment is virtual reality (VR). NTT has developed a VR system that enables the user to experience the pitcher's form and the ball's trajectory from the batter's line of sight in three dimensions [6, 7]. With this system, we are able to create experimental conditions that cannot technically or ethically be produced in a real environment such as the smart bullpen. For example, a VR system enables us to manipulate information on the pitcher's form or ball movement for a certain purpose or to create a dangerous situation such as a ball flying toward the batter's head and to then analyze the batter's response to such situations.

The fourth type of experimental environment is a laboratory for conventional cognitive brain science. In this environment, we can present precisely designed visual, auditory, and haptic stimuli and accurately measure arm and eyeball reactions, brain activity, and other data. Here, a participant is fixed in a chair facing equipment and asked to deal with very simple tasks, so this environment is far removed from an actual sports scene. On the other hand, it is geared to fundamental experiments that enable specific factors to be isolated and analyzed in detail.

As described above, these four types of experimental environments each have their advantages and disadvantages. Which to use should be decided based on the current research objective.

3. Adjusting implicit brain functions

The second objective of SBS as described above is to actually improve the performance of athletes based on scientific knowledge related to the implicit brain functions of top athletes. To this end, there is a need for some means of adjusting implicit brain functions in order to improve performance. Conscious control of implicit brain functions is difficult, and verbalizing them is likewise hard. As a consequence, giving verbal instructions to athletes can hardly achieve results. The athlete needs to objectively grasp his or her state of performance and intuitively understand points to be corrected or the direction of change. For this reason, we are working at SBS to present information on movements through sensory feedback by visual or auditory means.

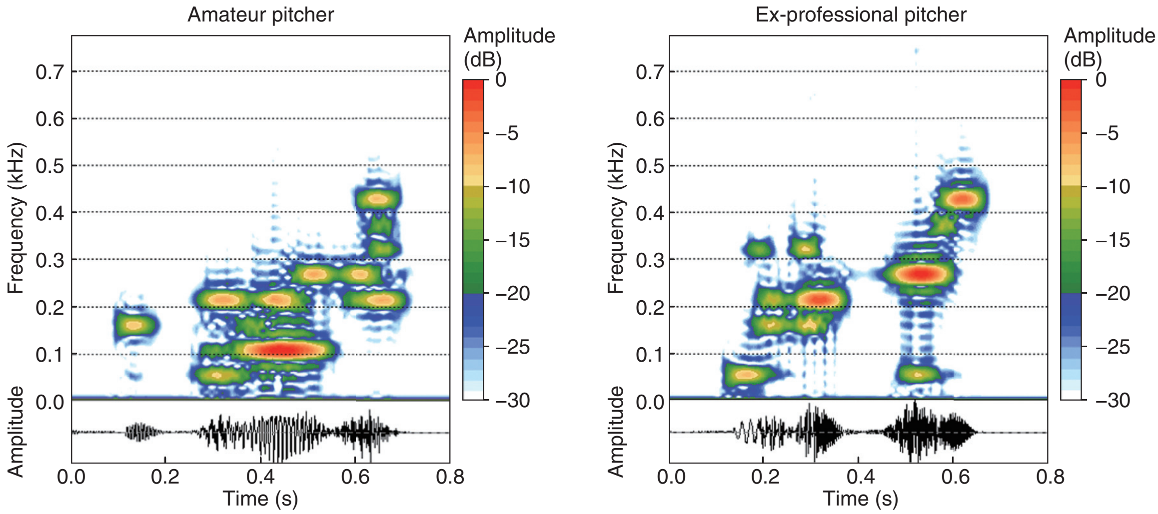
For example, we can use a large-screen display installed in the smart bullpen to present video of a pitcher's form captured with multi-angle cameras together with data such as the ball's speed and spin several seconds after the delivery. In this way, pitchers can check their movement and the result directly after throwing the ball while their sensation of the pitch still remains. Users have commented that this system helps them to become aware of the gap between subjectivity and objectivity, which is a common problem for athletes, while providing them with an opportunity to make appropriate corrections.

We have also developed a sonification system that converts actions such as pitching a ball into sound based on information received from wearable myoelectric sensors and acceleration sensors attached to various parts of the body (**Fig. 3**) [8]. While differences in form can be easily understood by video, the amount of applied force and the timing can be easily understood by sound. This system can therefore help the athlete to intuitively understand the difference between a model action and one's own actions, and the difference between one's good form and poor form. We will continue to research methods of intervention using VR.

4. Future outlook

In SBS, our two objectives of understanding an athlete's implicit brain functions and improving performance constitute our basic policy around which our work revolves. It is a general rule that a big gap will exist between basic research in the laboratory and improving athletic performance in the field. To overcome this gap, we have adopted a style that enlists the cooperation of top athletes and teams to develop an awareness of real problems in the field and uncover seeds for basic research. In this way, we can promote athlete-centered research and not just research for research's sake. We must strictly avoid having a negative effect on athletes by simply intervening. To intervene on scientific grounds, a large volume of high-quality data is needed, and at the same time, a cooperative relationship with athletes is essential.

Progress in research in SBS will help to systemize a methodology for winning based on scientific grounds in relation to brain characteristics. As part of this progression, there will no doubt be findings that diverge from what has so far been considered common sense. Inside a facility like a smart bullpen, athletes can develop an understanding of their own state, including things that they are not normally aware of, and identify points for improvement. Such a facility may also help to change one's behavior or form or detect signs of injury. In addition, accumulating data



Information received from wearable myoelectric sensors attached to 8 parts of the body is converted into a pattern of sound.
Upper panels: sound spectrograms, lower panels: amplitude waveforms

Fig. 3. Sonification of pitching action.

on many athletes will make it possible to diagnose individual type, aptitude, level, and other factors. It will also facilitate coaching oriented to individual conditions and enable early discovery of talent.

In SBS, we are presently focusing on the sports of baseball and softball, but we feel that the knowledge gained here can be essentially expanded to other sports. Furthermore, we are now targeting only top-level athletes such as those in professional baseball and the Japanese national softball team or an equivalent level, but in the future, we would like to broaden our target level to include junior athletes and even devoted sports fans and the elderly. More details on our research and progress to date can be found on the SBS website [9].

Acknowledgment

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Trademark notes

Makio Kashino

Senior Distinguished Scientist/Project Manager, Sports Brain Science Project, NTT Communication Science Laboratories.

He received a B.A., M.A., and Ph.D. in psychophysics from the University of Tokyo in 1987, 1989, and 2000. He joined NTT in 1989. From 1992 to 1993, he was a visiting scientist at the University of Wisconsin (Prof. Richard Warren's laboratory), USA. He is currently a specially appointed professor in the School of Engineering, Tokyo Institute of Technology. He has been investigating functional and neural mechanisms of human cognition, especially auditory perception, cross-modal and sensorimotor interaction, and interpersonal communication through the use of psychophysical experiments, neuroimaging, physiological recordings, and computational modeling.

Sports Brain Laboratory for Measuring Athletic Competence and Performance

Masumi Yamaguchi

Abstract

Collaboration with athletes is essential for carrying out the Sports Brain Science project, a recent NTT initiative. This project aims to create novel insights into human science as well as to enhance athletic performance and thus benefit both researchers and athletes. The project is introduced in this article, focusing on the research facilities.

Keywords: hitoe, baseball, laboratory

1. A laboratory designed to attract athletes

The Sports Brain Science (SBS) project was initiated to create a novel research field by combining three of NTT's strengths: the human and brain science being studied at NTT Communication Science Laboratories; the vital sensing fabric called "hitoe," developed from bioscience research carried out at NTT Basic Research Laboratories and first commercialized as sportswear in 2014; and information and communication technology, a basic technology of NTT (**Fig. 1**).

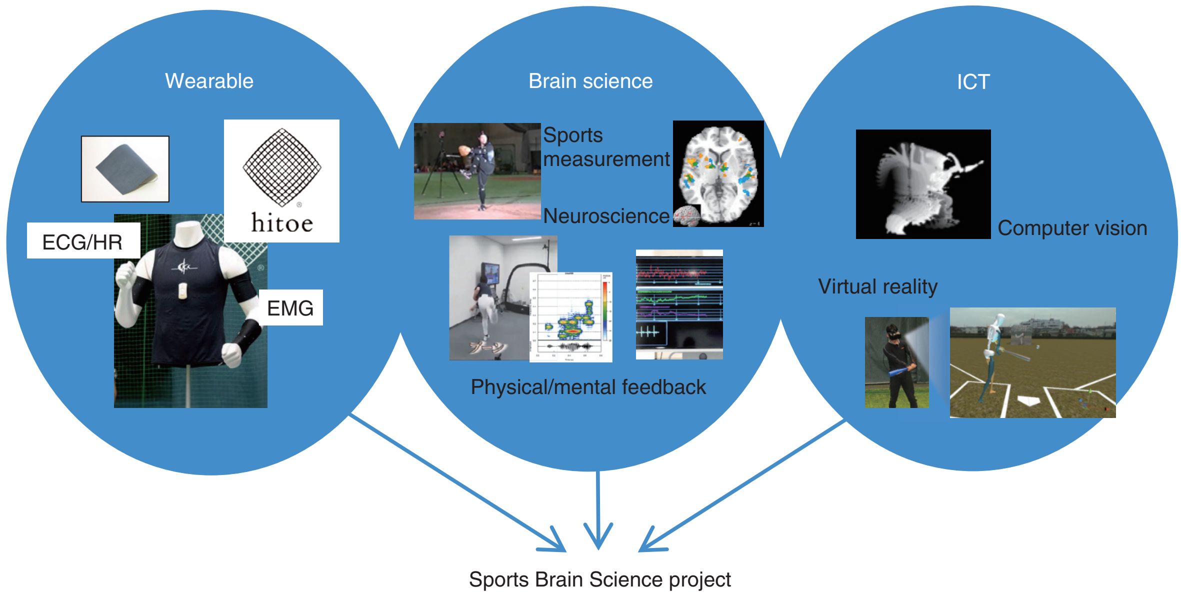
At the beginning of the project, researchers conducted simple experiments such as measuring electromyograms of men throwing balls to a batting tee net or putting golf balls on a pad in a small room. In 2015, we began work on a specialized facility dedicated to conducting authentic sports experiments. This facility was located in an empty space that used to be the synchrotron radiation (SOR) facility at the NTT Atsugi R&D Center [1].

The SOR equipment was moved out in 2015. The total area of the space is 20 m x 30 m with a ceiling height of 11 m for most of the space. Researchers first built a baseball pitching mound from clay and concrete blocks. A former professional baseball pitcher, who is collaborating with us in the project, came to the laboratory to throw balls from the mound. He acknowledged the researchers' construction effort but said that the mound was too small for throwing by professional players.

Although we realized that the mound should be extended, we were not up to the task of molding ten tons of clay into a real pitching mound. When we discussed this issue with the planning section, the laboratory director authorized the construction of a real pitching mound, adding that we should create a sports laboratory that athletes would want to visit again and again.

This meant that the laboratory should be planned not only to facilitate data collection but also to provide an attractive environment for athletes. Because athletes dedicate much of their lives to improving their performance, it was necessary to construct a facility enabling us to carry out experiments on athletes' performance without hindering their training.

From a basic research point of view, we wanted our experiments to have long-term benefits for athletic events, but we also thought it was important to generate short-term benefits for the athletes participating in our experiments. The idea of a laboratory that athletes would want to visit repeatedly was the guiding principle in designing the laboratory and also in planning and conducting the research. The Sports Brain Laboratory (SBL) was completed in March 2016 (**Fig. 2**), and we are continuously improving the facilities



ECG: electrocardiogram
EMG: electromyogram
HR: heart rate
ICT: information and communication technology

Fig. 1. Elements of the Sports Brain Science project.

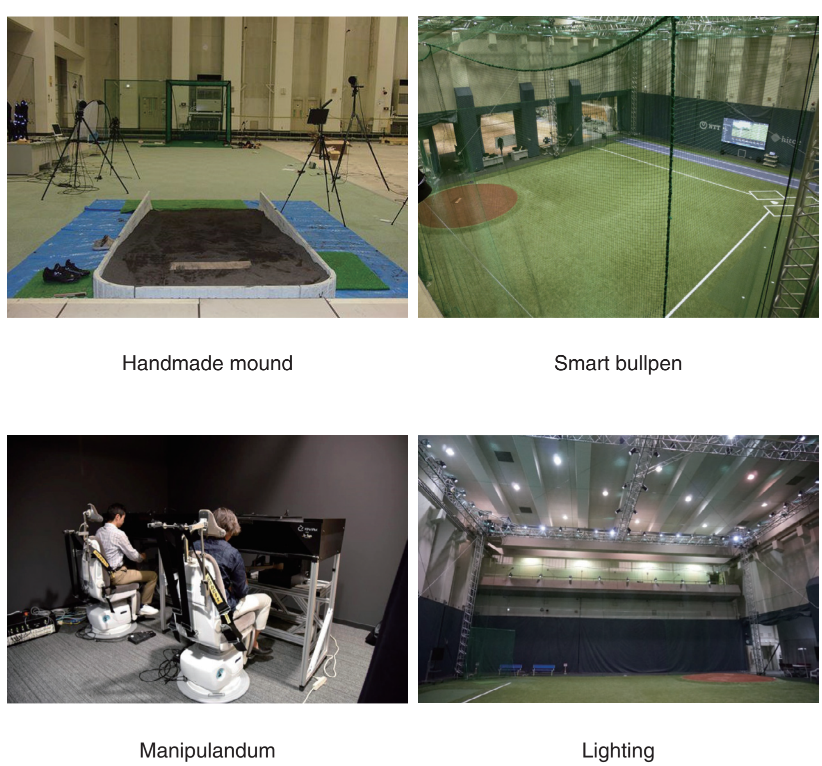


Fig. 2. Sports Brain Laboratory.

Fig. 3. Displaying the performance and multi-angle videos.

while using them for various experiments.

2. Smart bullpen

Of particular importance in designing the bullpen was achieving one that would enable the players—the pitcher and batter—to play seriously. One of the skills we are focusing on is batting, where we are seeking to understand the implicit brain function within the 0.5 seconds before the ball arrives at the home plate after the pitcher releases it. The best way to study this is to take measurements during real games. However, this is impractical because of the game's regulations and field rules. Therefore, we prepared a smart bullpen where the pitcher and batter can play as if on a real field, and many kinds of data can be collected. High-speed video, pitching speeds, trajectories, and spins of balls obtained by radar, as well as video from the front, sides, and top are taken as players play realistically in the smart bullpen (**Fig. 3**). In addition, when players wear a motion-sensing suit and "hitoe" shirt, motion data and biological data such as heart rate can be measured.

Live video with a delay of a couple of seconds, as well as pitching performance such as speed and spin, can be displayed on a large monitor installed in front of the mound on the left. Normally, such data are not shown to subjects during experiments because their actions—and thus the experimental results—may be affected. In our laboratory, however, athletes use the monitor to check their own motion and performance during breaks between and after experiments. The video and measured data are used not only for research data but are also provided as feedback to the athletes, enabling them to review their motion and performance.

3. Facilities of SBL

The SBL includes measurement equipment for use in research on other sports and activities such as golf and walking. The space within the SBL is limited, so the configuration of equipment was determined on the basis of input from every researcher involved. For example, the golf tee, where two force plates are used to measure shifts in weight, is located at the right corner from the bullpen in order to obtain the longest shot distance. The area where the ceiling is lower is used as a gym floor for virtual reality experiments (**Fig. 4**) and for basic biomechanical experiments done with a treadmill and manipulandum system.

Although the SBL was expertly designed for various experiments, we initially overlooked the importance of lighting. Since the laboratory was already bright enough for normal activity, and taking video was not emphasized, no one recognized the need to enhance the brightness of the room. The importance of lighting was pointed out by an expert in sports broadcast lighting who happened to visit our lab with the designer we consulted. He said that lighting is of

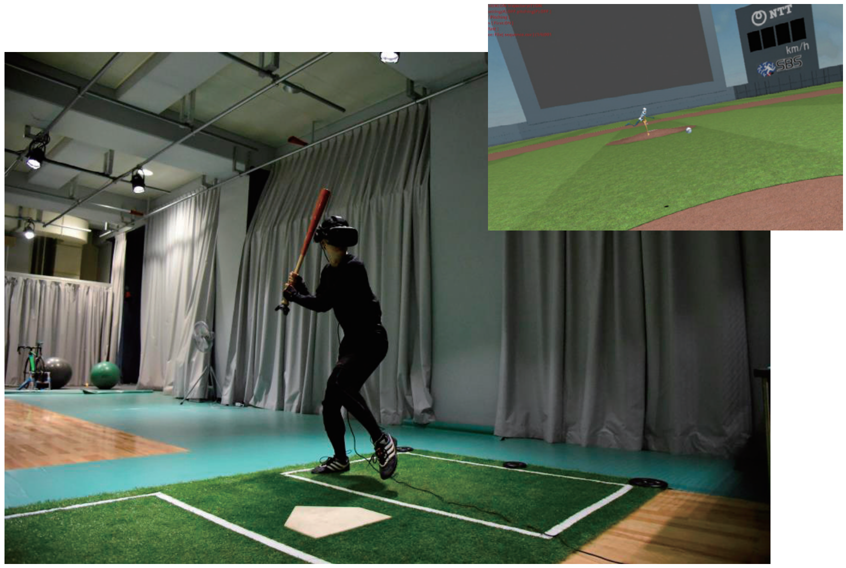


Fig. 4. Batting experiment using virtual reality.

fundamental importance for the laboratory. This became evident when we faced a flicker problem when using the high-speed camera. In most cases, it was difficult to add support lighting around the bullpen because the balls that are hit fly around the bullpen during experiments. Therefore, we used light emitting diodes (LEDs) to increase the brightness of the laboratory light. The LEDs are compatible with the high-speed camera and make the SBL as bright as the infield during a professional night baseball game.

We later found that the lighting was important not only for obtaining good experimental data but also for ensuring the high quality of the feedback video for athletes. To make the SBL more viable, we are continuously modifying it by taking into account the opinions from various professionals and the demands of researchers and athletes.

4. Smart sensing with "hitoe"

Another important objective of our project other than the basic research of sports brain science is to establish smart sensing skills using "hitoe" in sports scenes. The functional material "hitoe" is a conductive fabric that enables us to measure electrocardiograms and electromyograms by using it as a sensor electrode on human skin. Consequently, electrical signals are generally sharper and more stable compared to pulse signals. In addition, one of the major advantages of "hitoe" is that its hydrophilic property enables low-noise measurements even when subjects are sweating during hard practice.

A remaining important issue, however, is determining how to configure the transmitter and loggers on the body. It is necessary to configure them so that they do not disturb the athlete's activity. For example, in the case of C3fit IN-pulse*, a transmitter set at the chest sends data to smartphones via Bluetooth Low Energy (BLE). We have so far performed heart rate measurements at a baseball game in an attempt to visualize the mental tension of the pitcher using "hitoe" [2]. For these measurements, the pitcher wore a small smartphone as well as the transmitter because it was difficult to send the small BLE signal outside of the playing field. This solution was only applicable to practice matches. Furthermore, the operation of the smartphone would disturb players, even if the rules of the game allowed them to wear a smartphone.

To solve this problem, we are developing a system that automatically measures the athletes' biological signals when they are inside the SBL. This is done by having them wear "hitoe" smart wear. This system is based on the same wireless technology used in the rehabilitation institution introduced in this journal [3]. In the future, we will develop and implement the same kind of system in a real baseball stadium.

* C3fit IN-pulse: Brand name of a sportswear-type device using "hitoe" supplied by GOLDWIN since 2014. One's heart rate and electrocardiographic waveform can be measured by wearing it.

5. Future development

Although measurement tools are now smaller and smarter than ever, the measurements themselves still impose a psychological load on some athletes. A coach of junior high school aged athletes told us that getting used to such measurements at a young age is important because athletes would then be able to undergo them without any undue psychological stress when they had reached the top level in their sport. We were impressed with his long-term training vision and expectations regarding our scientific approach. Our goal is to train athletes' brains for winning, but this cannot be achieved only by researchers. Collaboration with athletes as well as with coaches and staff is necessary for our project's success. By creating the appropriate environments and having a research vision that makes athletes want to participate, we are putting forward projects to gain novel insights into human science and to assist athletes in attaining victory.

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Trademark notes

Masumi Yamaguchi
Senior Research Scientist, Molecular and Bio Science Research Group, NTT Basic Research Laboratories, and Sports Brain Science Project, NTT Communication Science Laboratories.
He received a B.S. in physics from Kanazawa University in 1998 and an M.S. and Ph.D. in physics from Kyoto University in 2000 and 2003. He joined NTT Basic Research Laboratories in 2003. He has been part of the Sports Brain Science project since 2016. He is a member of the Physical Society of Japan, the Japan Society of Applied Physics, and the Institute of Electronics, Information and Communication Engineers.

Timing Adjustment of Baseball Batters Determined from Motion Analysis of Batting

Daiki Nasu

Abstract

It takes only 500 ms for a baseball to reach the batter after it leaves the hand of the pitcher. We at NTT Communication Science Laboratories set ourselves the task of figuring out how information is processed in the mind of skilled hitters, enabling them to respond and hit the baseball within this extraordinarily brief interval of time. Here, we explore the information processing time structure in the brain of a batter using motion analysis technology during actual pitcher-batter match-ups.

Keywords: athlete, motion analysis, timing control

1. Challenge of hitting a baseball

A baseball batting average of .300 in a season is quite respectable, considering that no player has ever reached an average of .400 in the entire history of professional baseball in Japan. A .300 average means that the batter safely gets a hit three times for every ten times at bat. One might initially assume that the pitcher has an obvious advantage, but actually this reveals a fascinating aspect of the game. The batting average can be attributed to the distance that separates the pitcher from the batter, traditionally established as 18.44 m. When the ball is thrown at a velocity of 140 km/h, it takes only about 500 ms for the ball to traverse this distance. The batter must determine within a split second precisely when and where the ball is going to cross the plate, then spatially and temporally synchronize his swing to connect with the ball.

What sort of processing and control goes on in the batter's mind and body to achieve this enormously difficult motor task has long been a subject of fascination, but the mechanism remains elusive. We explored this issue by conducting precise measurements of the batter's motions when he was squared off at the plate facing a pitcher. In this article, we share some of our findings and reveal the timing structure of batting when the batter is facing an actual pitcher [1].

2. Measurement of motion in pitcher-batter match-ups

In batting, there are two critical factors that the hitter must keep in mind: the *temporal factor*—how long it takes the ball to reach the plate after it leaves the hand of the pitcher—and the *spatial factor*—the trajectory of the ball as it approaches the plate. Let us first consider the temporal factor by measuring and analyzing the batter's movements when hitting two types of pitches: straight fastball pitches and off-speed changeup pitches*. A changeup is actually a slow pitch that is meant to deceive the batter into thinking it is a fastball and thus throw off the batter's timing.

The data gathered in this study were derived from two former professional baseball players—a pitcher and a batter—as subjects, both of whom were right handed. The trials were conducted by having the batter

* Motion was measured in this work using an inertial sensor motion capture suit (MVN Biomech Link manufactured by Xsens) at a sampling rate of 240 Hz. With the MVN Biomech Link suit, we were able to capture hitting and pitching action in the field and unrestrained swinging action of the subject without the use of a camera.

Table 1. Information on typical pitches and bat swings.

Pitch type	Ball speed (km/h)	Time from pitcher's ball release to bat contact (ms)	Swing speed (km/h)	Outcome
Fastball	123.9	496	114.4	Strong hit
Changeup	103.7	579	124.4	Strong hit
Changeup	109.9	533	106.0	Miss

swing and try to hit the balls thrown by the pitcher from the mound (at a regulation distance of 18.44 m from the plate) toward the catcher behind the plate. The order in which the two types of pitches (changeups or straight fastballs) were thrown was randomly determined by a computer, so there was no way for the batter to anticipate which type of pitch was coming next.

The pitcher threw the ball at velocities ranging from 125.1 km/h for straight fastballs (standard deviation 2.6 km/h) to 101.3 km/h for changeup pitches (standard deviation 4.5 km/h), so from pitcher's hand to hit, the ball was in the air for an average of 451 ms for straight fastballs (standard deviation 10 ms) and for 581 ms for changeup pitches (standard deviation 22 ms).

For the purposes of this discussion, we will consider three typical swings as illustrated in **Table 1**: a power swing that hits a straight fastball, a power swing that hits an off-speed changeup, and a swing that misses a changeup pitch.

3. Batting time structure

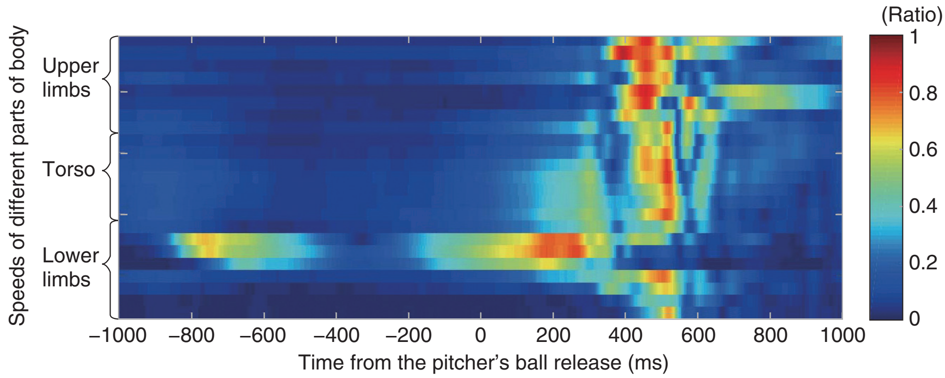
Let us first consider the batter's swing motion in addressing a straight fastball as the basic batting motion structure in baseball. A heatmap representing relative speeds of different parts of the batter's body is shown in **Fig. 1(a)**. This heatmap makes it easy to recognize the overall spatiotemporal structure. To make it easier to see what is going on, the findings are presented as a ratio of the data to the maximum speed of different parts of the batter's body to the time of the ball release, within the range of analysis (*i.e.*, 1000 ms before and after the pitcher releases the ball). The red portions in the figure represent faster movement.

In **Fig. 1(b)**, we can see time waveforms and characteristic event times for speeds of different parts of the batter's body: lower limbs, torso, and upper limbs. The batter estimates the timing as he raises his forward leg in synch with the pitcher's motion, then steps out with his forward leg as he shifts his center of gravity. About 350 ms after the ball has left the pitcher's hand, the batter plants his forward foot, stops the shift in the center of gravity, and increases the speed of his upper limbs (*i.e.*, his arms) while rotating his torso. One can see that a power hit involves a chainlike transmission of energy that begins in the legs and is transmitted to the torso, then to the player's arms, and finally to the bat in the form of bat head speed [2]. The characteristics of this movement, the so-called *kinetic chain*, are not confined to batting but are a fundamental sequential motion in many hitting and throwing sports. For example, they also exist in the swinging of a golf club, smashing the badminton birdie, and other maneuvers [3].

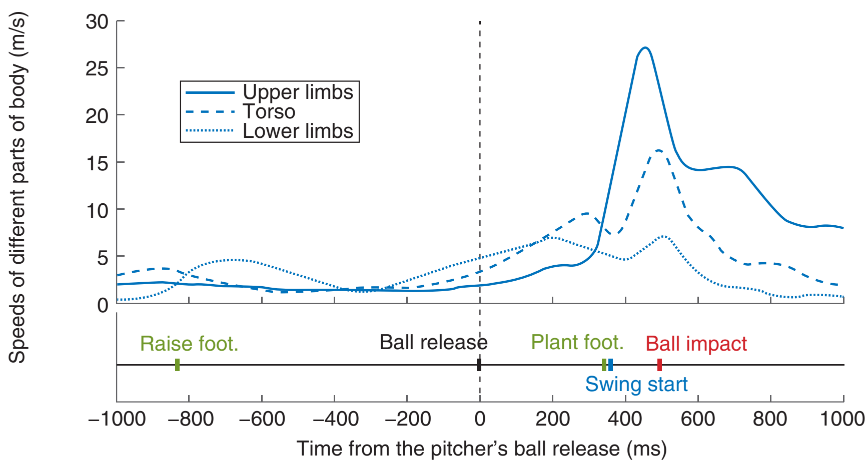
4. Changeups: when and how to respond?

Since there is no way for the hitter to know in advance if the next pitch will be a straight fastball or an off-speed changeup, he typically takes the stance of a player anticipating a fastball [4]. When the batter begins a swing motion expecting a fastball but then realizes the pitch is a changeup, he has to adjust his timing to fill the additional 90 ms before the ball reaches him, which thus requires a so-called pause (*tame*).

Once committed to a continuous swing, when and how is the batter able to adjust his movements? A comparison of the timing of successful swings for a changeup hit and a fastball hit is shown in **Fig. 2**. If one focuses on the velocity waveform of the batter's arms and the event timing, it is apparent that the batter delays the beginning of his swing when faced with a changeup, which means that the impact timing is also delayed. When the hitter's legs and torso turn, one can see that the waveforms are more or less the same regardless of pitch for approximately the first 300 ms after the ball is released from the pitcher's hand, but a change suddenly occurs as highlighted by the arrow in Fig. 2. The movement of the player's torso region (long dashed lines) abruptly slows when



(a) Heatmap



(b) Time waveforms

Fig. 1. Time structure of baseball batting.

dealing with a fastball but continues at the same speed when addressing a changeup pitch. Finally, in **Fig. 3**, we observe a downward motion in the movement of the batter's hips. In other words, the batter steps out with his forward foot while lowering his center of gravity; then when responding to the changeup pitch, he continues the downward shift, which allows him to adjust his foot placement timing and delay his swing.

In the case of a missed swing, the waveform is practically identical to the straight fastball hit; the batter stops shifting his torso downward, plants his leading foot, then goes into a swing with the same timing as when addressing a straight fastball. Thus committed, the batter is unable to adjust his timing to the slower changeup and misses the ball.

The data in Fig. 3 reveal that the batter begins to adjust his movement for a changeup pitch about 300 ms after the ball leaves the pitcher's hand. It takes another 150–200 ms for the batter to physically respond after visually confirming that the pitch is a changeup. Under the assumption that the batter obtains visual confirmation of a changeup and responds within 150 ms, the information needed to make a decision must be obtained within 150 ms after the ball leaves the pitcher's hand, which is equivalent to a travel distance of about 5 m in the air. Baseball coaches are fond of telling their players to keep their eyes on the ball until the bat makes contact with the ball, but with the limitations of human vision and reaction time, information about the latter half of the ball's trajectory is completely useless.

Although the findings presented here are based on a single former professional baseball player, we

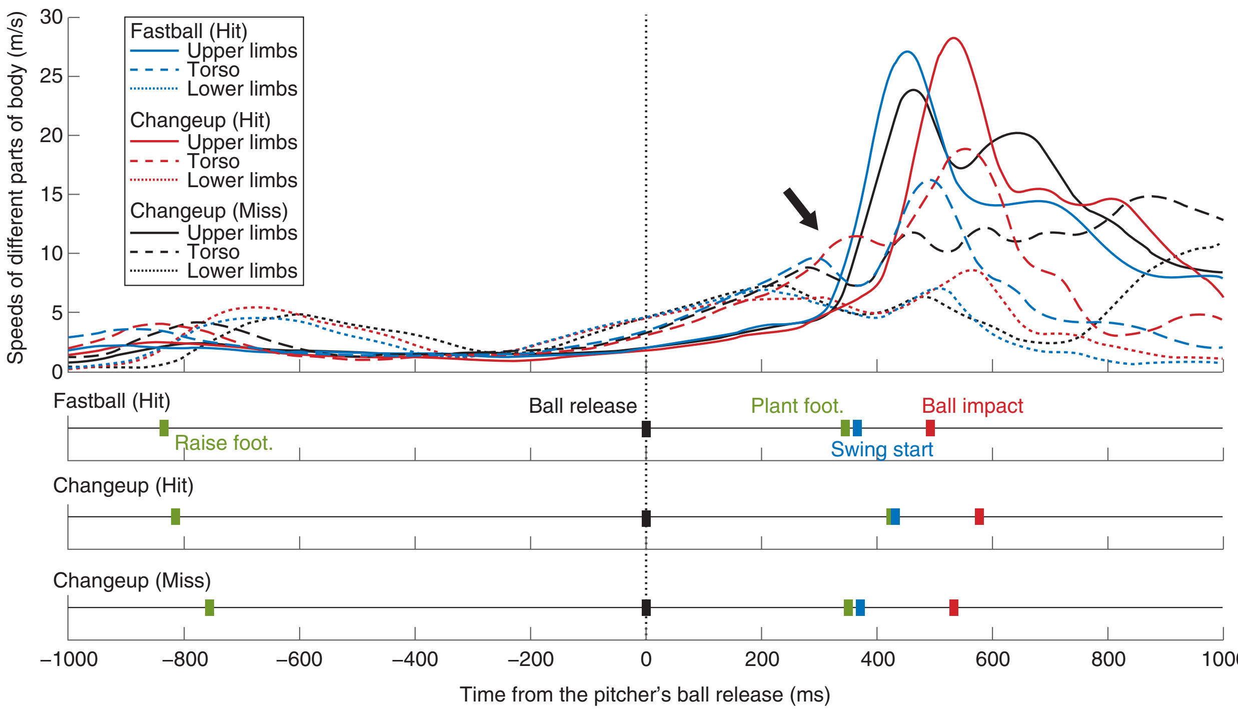


Fig. 2. Speeds of different parts of batter's body and characteristic event timing.

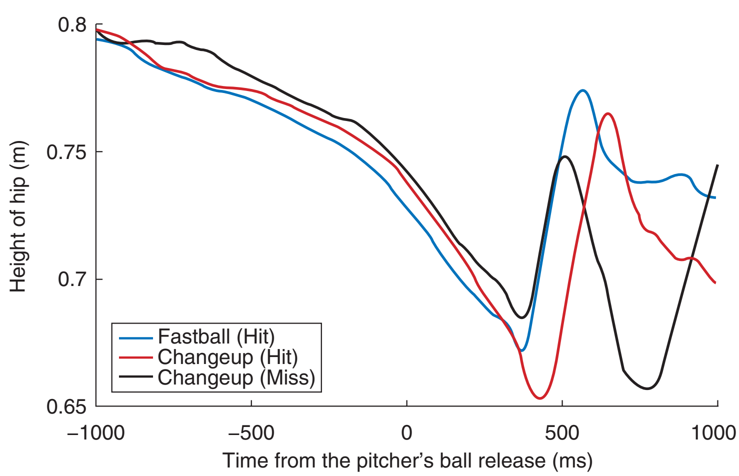


Fig. 3. Height of batter's hip and ball release timing.

obtained identical results for another former professional baseball player when measured under the same conditions. In other words, we observed the same shift in timing as the second player lowered his center of gravity about 300 ms after the ball left the pitcher's hand. Even more interestingly, we observed the same timing shift at 300 ms after the ball was released for a woman batter on a professional softball team. Our findings reveal that within a time frame of about 500 ms, figuring out how to obtain information enabling the hitter to make a decision (or from the pitcher's perspective, how to prevent the hitter from obtaining this information) within 150 ms after the ball leaves the pitcher's hand—after subtracting the time needed for the batter to adjust his stance based on visual confirmation of the pitch (about 150 ms) and the time needed for the batter to follow through with a swing (approximately 200 ms)—is critically important in determining whether the batter actually hits the ball or swings and misses.

5. Future development

This study focused on the critical time frame of a pitch lasting about 150 ms after the ball leaves the pitcher's hand. During this 150-ms window, the pitcher's pitching form and the trajectory of the ball are important pieces of information, but which is more important in helping the batter decide how to deal with the approaching pitch is not at all clear. To help answer this question, we are conducting a study using virtual reality (VR) technology as part of this project. VR gives us the ability to freely manipulate both the pitching form and the trajectory of the ball, so we can measure the batter's response in the same way as having the batter swing at pitches on a baseball field. With the addition of VR, we expect to corroborate the study's findings.

This study marks an important first step in identifying the mechanism involved in triggering motor tasks as whole-body movements within extraordinarily short reaction times of less than 500 ms as faced by batters on the baseball diamond. Gaining a clear understanding of how skilled hitters are able to move and maneuver when they are at the plate will provide valuable clues as to what to focus on in the future work in order to really comprehend this split-second reaction timing. To examine these elements in greater detail, we are employing VR, scrutinizing the motor tasks involved in maneuvering the arms, and conducting periodic measurements of brain activity. We are convinced that this approach will bring us a clearer understanding of the fundamental mechanism involved in batting.

We would also note that the analytical approach described here could be readily adapted to the onsite needs of capturing and assessing the performance of individual players. Even the limited task we set ourselves here of dealing with changeup pitches has produced some interesting results. We are now beginning to understand the different strategies players have for dealing with changeups, some of which are successful and others less successful, and feeding those insights back to the teams that we support and work with. Continuing to build on these efforts will enable us to directly aid and support the actual game on the field while at the same time contributing to further development of sports and brain science.

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Daiki Nasu
Sports Brain Science Project, NTT Communication Science Laboratories.
He received a Ph.D. in medicine from the Graduate School of Medicine, Osaka University, in 2014. He joined NTT Communication Science Laboratories in 2016. He has been engaged in research on human motor control and biomechanics in sports. He has recently been focusing on the relationship between sports performance skill and brain function in athletes. He is a member of the Society for Neuroscience, the Japan Society of Physical Education, Health and Sport Sciences, the Japanese Society of Biomechanics, and the Japan Society of Baseball Science.

Virtual Reality-based Sports Training System and Its Application to Baseball

Dan Mikami, Kosuke Takahashi, Naoki Saijo, Mariko Isogawa, Toshitaka Kimura, and Hideaki Kimata

Abstract

This article introduces a system we are developing that provides a first-person-view experience to users. It is aimed at preparing athletes to engage in sports competitions by enabling them to experience game situations from their own point of view before the game. The use of video has rapidly become popular in the sports field in various ways such as for scouting the opposing team before the game. Such videos are usually captured from a position different from that of players while they are playing the game. Thus, they cannot simulate the game very well. Our system provides a virtual reality-based first-person-view experience by using information captured or measured from locations that will not disturb the game. We describe in this article how our system worked in a trial with a professional baseball team.

Keywords: VR, sports training, baseball

1. Introduction

The use of information and communication technology has rapidly permeated into sports in recent years. One of the most popular uses is statistical analysis and its visualization because of the easy correspondence to big-data mining and broadcasting. In baseball, statistical analysis verifies factors that correlate to victory. One such type of analysis is known as sabermetrics and is mainly used for evaluation and recruiting in team operations.

In contrast, our research mainly focuses on supporting individual athletes to help them perform at their best. For sports in which players directly confront each other, for example, baseball, tennis, and soccer, it is important to not only improve the player's own skill but also to help players adjust to their opponents. We believe that this will be especially important for professional athletes because of the high skill level of their competitors.

For athletes to perform at their best in a game or sport, it is important for them to know their opponent. Video-based scouting has been popularized for this purpose in recent years. It enables intuitive understanding of the opposition, which words or statistics cannot easily provide.

However, there are limitations to what can be achieved with the current video-based scouting. One such limitation is viewpoint. Because the scouting video is captured from outside of the baseball field, the viewpoints of the actual game situation and of the scouting video are different. Because of this difference, the scouting video does not fully support athletes in their pre-game or pre-sport preparation.

To address this, we tackled the problem of how to generate and provide a first-person-view experience before the game or sport was actually played. We have mainly focused on the sport of baseball in this article because it is one of the most appropriate ways in which the technology can be applied.

2. Background

In this section, we briefly explain some key features

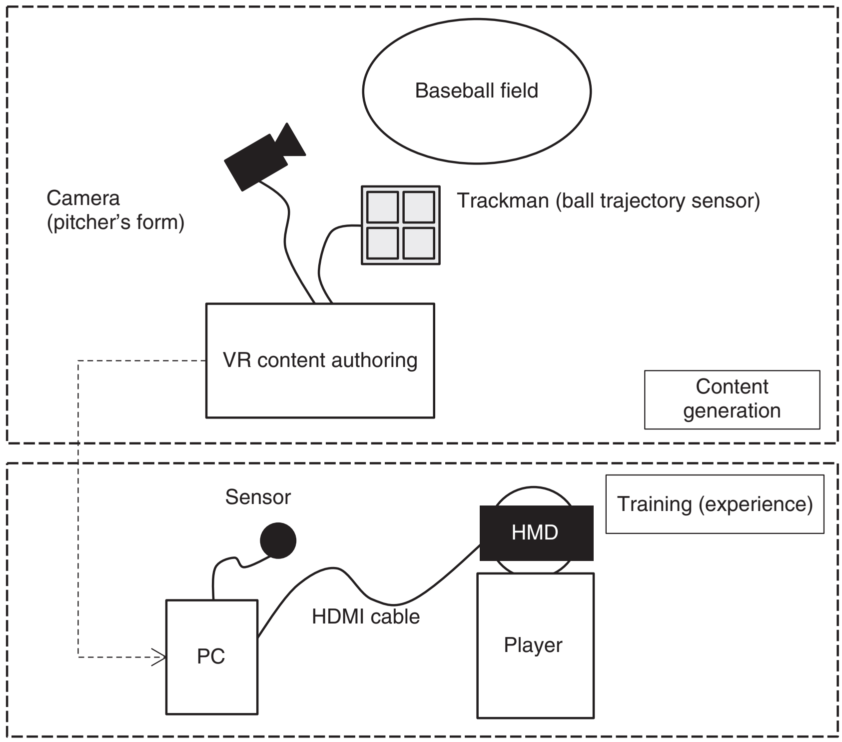

Fig. 1. Structure of VR-based imagery training system.

of batting in baseball and then discuss the required elements of the technology we are developing.

2.1 Features of baseball batting

A baseball game always starts when the pitcher throws the ball to the first batter. During a game, starting pitchers usually throw about 100 pitches, and batters typically have about three opportunities at bat. Therefore, the batters have to adjust to the way the pitcher throws the ball during the game. Radio broadcasters commentating on the game are likely to report on how batters adjust to the way the pitcher throws the ball the second or third time they face the pitcher. Batters can therefore use what they have learned from virtual reality (VR)-based technology to improve their batting performance.

2.2 Definition of requirements

We held discussions with professional players and coaches to determine the necessary capabilities of the system. We extracted the following four requirements:

(1) The system can provide the ball trajectory with depth information.
(2) The system can reproduce the correct ball trajectory at arbitrary positions within the batter's box.
(3) The system can be taken to any place and set up easily.
(4) The system can be updated with the latest information about the pitcher.

In the next section, we describe the system we propose that fulfills these requirements.

3. VR-based imagery training system

The system structure is depicted in **Fig. 1**. The proposed system consists of two phases: a generation phase and an experience phase. The generation phase generates an experience in a three-dimensional (3D) virtual space based on a pitcher's motion and on ball tracking. We use captured videos to represent a pitcher's motions, while the ball is depicted by computer graphics (CG) based on the measured 3D ball position.

The experience phase provides an experience to

Fig. 2. Example snapshot of batter's view.

users through a head mounted display (HMD). The position and orientation of the HMD are measured so that the view that is rendered to the user changes depending on the user's posture. We used Oculus Rift as the HMD. Another well-known HMD with position tracking is VIVE, but we selected the Oculus Rift model because it is lighter. An example snapshot of a batter's view wearing the HMD is shown in **Fig. 2**. In actual use cases, the HMD displays two different images to each eye to provide parallax.

The system that we briefly introduce here effectively provides the correct ball trajectory from arbitrary viewpoints, and it can be used in arbitrary places because the HMD we adopted is highly portable. We describe the generation phase in the next section. This is the main contribution of this article from a technical aspect and mainly focuses on how easily updates can be made by using the latest information.

4. Generation phase

The generation phase updates VR content with the latest information. This makes it easy even for non-experts to update operations while maintaining stable quality. We adopted a hybrid approach that combines a billboard representation of a pitcher and a CG-drawn ball at a measured 3D position.

4.1 Billboard-based pitcher representation

There are several possible ways to represent a pitcher in 3D virtual space. In one 3D CG example, the pitcher's posture and texture are measured. However, it is difficult to stably update VR content using this solution because pitchers will almost never permit their posture to be captured with a motion capture system. This is to prevent the opposing team from getting hold of such content and watching them before the game.

A well-known method called billboard-based video representation [1] does not rely on the pitcher's posture. Roughly speaking, one advantage of this method is that it mainly makes use of captured videos. Another advantage is that it can easily represent subtle nuances in pitchers such as changes in their facial expressions, which are very hard to measure and represent through the use of CG. We used these advantages to provide billboard-based representations of pitchers. First, we captured a video of the pitcher's motions from outside the playing field. We then placed a virtual panel (called a billboard) at the pitcher's location in a virtual stadium depicted by 3D CG. Finally, we played the captured video on the billboard. In baseball, the positions of the pitcher and batter do not significantly change. Thus, the billboard-based representation suits this task.

4.2 Representation of ball trajectory by CG

Unlike a pitcher's motion, the thrown ball is a significantly difficult target for the billboard approach to represent. This is because it includes large and abrupt position changes; a thrown ball moves about 18 m in about 0.5 s. Therefore, we do not use captured video directly to represent the ball. Instead, we first measure the ball trajectory and then use CG to render the ball. This solution enables us to provide an accurate ball trajectory at arbitrary positions from the batter's box area.*

However, a severe disadvantage occurs in combining billboard-based pitcher representation and

(a) Duplication of actual filmed ball and CG rendered ball

(b) Filmed ball has been removed

Fig. 3. Duplication of the filmed ball and the CG rendered ball, and the same image after removing the filmed ball.

CG-based ball rendering. That is, there is a duplication between the actually filmed ball and the CG rendered ball (**Fig. 3(a)**). To avoid this duplication, the filmed ball should be removed by image processing. We used the inpainting method proposed by Isogawa et al. [2] to remove the ball in the filmed video. We verified that it significantly improves the quality of experience, as shown in **Fig. 3(b)**.

5. Experiments and future direction

We verified the validity of our system with the cooperation of a team in the Nippon Professional Baseball (NPB) organization from two aspects. The first was the degree to which NPB players and coaches would accept it. The second was the system's operability, especially in updating VR content.

5.1 Acceptability

There are various indexes to evaluate batters; one of the most popular is batting average. However, we obtained users' (i.e., batters) subjective evaluations in a system trial conducted throughout a baseball season. This made it hard to make comparisons under a controlled setting. Furthermore, the task of successfully hitting a baseball is a quite uncertain one; a batter who gets a hit only three times in ten attempts is considered to be a very good hitter. This makes it very hard to evaluate the performance of our system on the basis of an objective score such as batting average.

(1) Depth sensing

Almost all professional baseball players have used videos to check out their opponents. However, watching videos on a 2D display does not give sufficient depth information since it provides neither binocular parallax nor motion parallax. In contrast, the system we propose reproduces 3D ball positions in virtual space and renders videos depending on the position and orientation of the HMD. It also renders them for both the right eye and left eye positions. Thus, it provides an HMD experience with depth cues, that is, binocular parallax and motion parallax. Many athletes who used our system said that with it, they really felt that the ball was coming from the pitcher.

(2) Simulation training for adjusting to pitcher's motion

Many batters say that it is very helpful for them to be able to see simulations of the opposing pitcher before the game. This enables them, for example, to check on how they will adjust to the pitchers' motions based on the changes the pitchers make in the speeds at which they throw the ball. They feel that this will allow them to make full use of their batting chances, even in their first time at bat.

(3) The system as a communication device

We received a comment from a staff member who said that using this system made it possible to expect better communication with players since both coaches and players could get the same ball trajectory.

However, some points arose that need to be addressed, including the low resolution provided due to the use of the HMD and the insufficient field of view for batting. One of the tasks we will tackle in the future is to carry out a more detailed analysis of the

* Ball tracking systems have been rapidly popularized in baseball stadiums. We believe it will be possible to accurately reproduce ball trajectories within a few years.

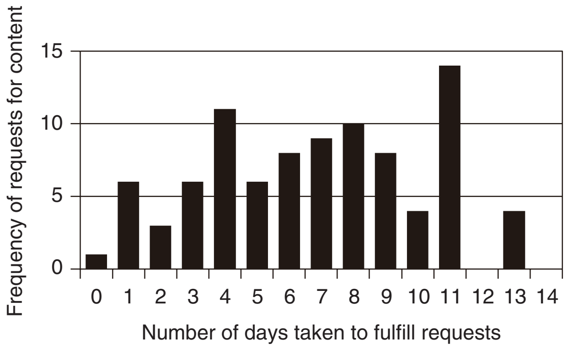

Fig. 4. Elapsed time between receiving a request for content from a team and the provision of the content.

system. The most important but most difficult thing we need to achieve is how to objectively measure the perceived correctness of the batter's experience. We will need to tackle this point to further develop the system.

5.2 Operation ability throughout a season

We conducted a trial of the system throughout the 2016 baseball season. The season comprised 143 games, but some of them were lacking in data to create VR content. Nevertheless, we created VR content for 96 pitchers, who threw an average of 15.6 pitches per game.

A histogram of the elapsed time between a request from a team for content and the time we returned the completed VR content to the team is shown in **Fig. 4**. Note that we could have returned the content sooner than we did if it had been necessary to meet the team's schedule. Sometimes, due to schedule changes or other factors, we were requested to provide content within a short time, even within a single day. The relatively high per-day submission frequency shown in the figure indicates that with our system we were able to handle such requests appropriately.

6. Summary

This article described a VR-based imagery training system we are developing and experiments we conducted on it in cooperation with a professional baseball team. We believe that our use of VR will provide people with advance experience in improving their actions in the real world. This will help them to make decisions under severe temporal constraints and thus will be helpful for various VR developers.

Future tasks will include clearly detailing factors such as HMD resolution, field of view angles, and system delay. This will make it essential to conduct experiments using athletes as subjects. We will attempt to carry out such experiments in a way that will mutually benefit the athletes and ourselves.

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Dan Mikami
Senior Research Scientist, Visual Media Project, NTT Media Intelligence Laboratories.
He received a B.E. and M.E. from Keio University, Kanagawa, in 2000 and 2002, and a Ph.D. from the University of Tsukuba in 2012. He joined NTT in 2002. His current research activities are mainly focused on computer vision and virtual reality. He was awarded the Meeting on Image Recognition and Understanding 2009 Excellent Paper Award 2009, the IEICE (Institute of Electronics, Information and Communication Engineers) Best Paper Award 2010, the IEICE KIYASU Zen'iti Award 2010, the IPSJ SIG-CDS (Information Processing Society of Japan, Special Interest Group on Consumer Devices & Systems) Excellent Paper Award 2013, and the IEICE Human Communication Award 2015.

Kosuke Takahashi
Research Scientist, Visual Media Project, NTT Media Intelligence Laboratories.
He received a B.Sc. in engineering and an M.Sc. in informatics from Kyoto University in 2010 and 2012. He joined NTT Media Intelligence Laboratories in 2012. His research interests include computer vision. He received the Best Open Source Code award Second Prize at the 2012 IEEE Conference on Computer Vision and Pattern Recognition.

Naoki Saijo
Senior Research Scientist, Sports Brain Science Project, NTT Communication Science Laboratories.
He received a B.E. and M.E. in mechanical engineering from Waseda University, Tokyo, in 1999 and 2001, and a Ph.D. from Tokyo Institute of Technology in 2010. He joined NTT in 2001 and has been engaged in research on human information processing. His research interests include human sensorimotor mechanisms, especially visuomotor control properties. He is a member of the Society for Neuroscience (SfN), the Japan Neuroscience Society (JNS), the Society of Instrument and Control Engineers, and IEICE.

Mariko Isogawa
Researcher, NTT Media Intelligence Laboratories.
She received her B.S. and M.S. from Osaka University in 2011 and 2013. She is currently a researcher at NTT Media Intelligence Laboratories and has been a Ph.D. candidate at Osaka University since 2016. Her research interests include computer vision topics such as image completion and quality assessment.

Toshitaka Kimura
Senior Research Scientist, Human Information Science Laboratory, NTT Communication Science Laboratories.
He received a Ph.D. in human neuroscience from the Graduate School of Arts and Sciences, the University of Tokyo, in 2003. He joined NTT Communication Science Laboratories in 2003. He has been engaged in research on sensorimotor control and action-perception interaction in humans. He has recently been focusing on brain functions in athletes and the use of information and communication technology in sports. He is a member of SfN, JNS, and IEICE.

Hideaki Kimata
Senior Research Engineer, Supervisor, High-Reality Visual Communication Group Leader, NTT Media Intelligence Laboratories.
He received a B.E. and M.E. in applied physics in 1993 and 1995 and a Ph.D. in electrical engineering in 2006 from Nagoya University, Aichi. He joined NTT in 1995 and has been researching and developing a video coding algorithm, visual communication systems, and machine learning. He is a Chief Examiner of IPSJ Special Interest Group on Audio Visual and Multimedia Information Processing.

Branched Optical Fiber Loss Measurement Technology for End-to-end Testing in Optical Access Networks

Hiroshi Takahashi, Chihiro Kito, Kunihiro Toge, and Tetsuya Manabe

Abstract

We have developed branched optical fiber loss measurement technology that enables us to measure branched fiber sections beyond optical splitters from a central office without entering the customer's premises. This article provides an overview of the developed technology and its application to the operation and maintenance of optical access networks.

Keywords: optical access, fiber loss, PON

1. Optical fiber measurement for optical access network maintenance

The number of fiber-to-the-home (FTTH) subscribers has reached approximately 29.30 million in Japan, about two-thirds of which—20.05 million—are with NTT EAST and NTT WEST. It is therefore important to reduce the cost of operating the huge amount of optical fiber that this system employs and ensure quality over a long period of time.

Passive optical networks (PONs) have been adopted for the majority of optical access networks. A PON has a topology where multiple customers share optical fibers using an optical splitter. PONs have contributed to achieving economic optical fiber network construction. On the other hand, they have also caused complications regarding the operation and maintenance of optical fiber equipment outside the central office, especially maintenance work involving the use of optical techniques for monitoring, testing, and identifying fibers.

Specifically, the optical signal used for maintenance and launched from a central office is equally divided by an optical splitter, so it is necessary to work from the customer side as well. Optical time domain reflectometry (OTDR) [1] is used for monitoring optical access networks from the central office side. However, since all backward scattered light beyond the splitter overlaps, it is impossible to perform the health monitoring and fault location in a section of branched optical fiber (**Fig. 1(a)**). In this case, measurement equipment is installed at the customer's premises to measure branched optical fiber sections, and the maintenance work requires the customer's presence. Moreover, redundant staff may be dispatched depending on the cause of the failure.

Additionally, there are similar cases when evaluating the link insertion loss (LIL) from the central office to the customer's premises, which is the most important characteristic of optical access networks, and the connection loss of the optical fiber. Similarly, when using a standard method to measure light such as the light source power meter (LSPM) [2] method or the bidirectional OTDR [3] method, it is necessary to measure from both the central office and the customer's premises (**Figs. 1(b)** and **(c)**). To evaluate

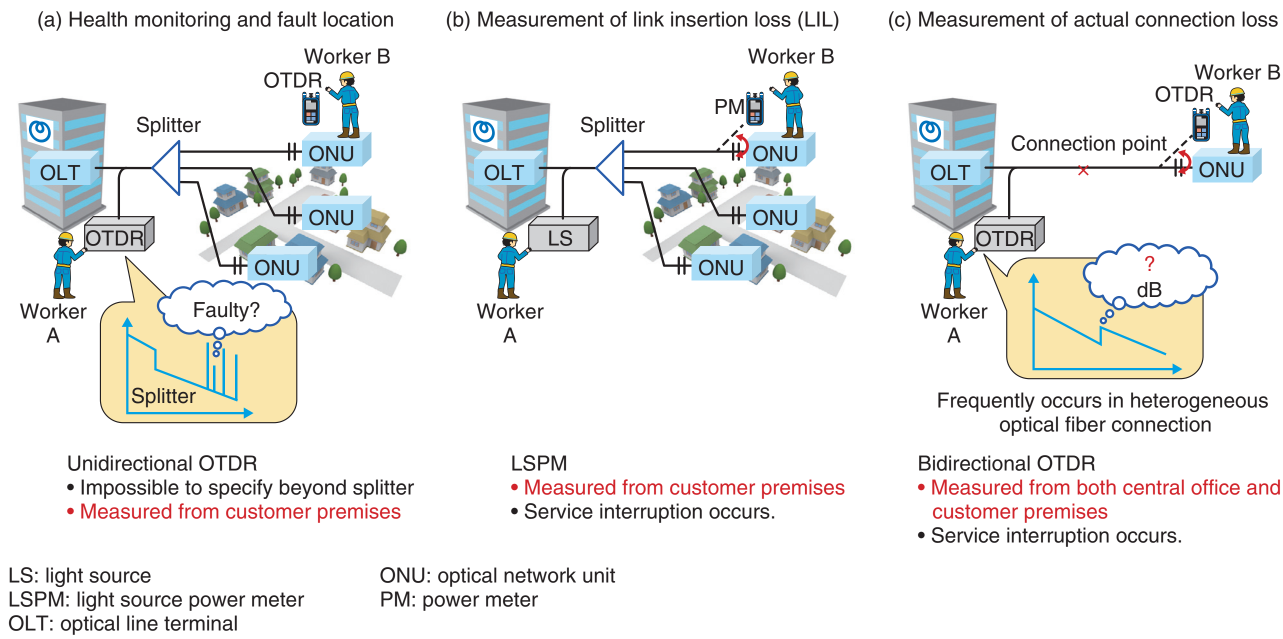


Fig. 1. Conventional optical measurement and its problems.

fiber quality after an investigation and fault repair, these measurements can be easily conducted when the customer is not present, such as during construction. However, measurements are difficult to perform when customers must be provided with certain services, for example, PON services.

Therefore, we have worked on developing a new optical loss measurement technology focusing on the characteristics of optical access networks, where one end of the optical fiber is located at the customer's residence, and where an optical splitter is installed.

2. Branched optical fiber loss measurement technique

A schematic diagram of our branched optical fiber loss measurement technique is shown in **Fig. 2** [4]. This technique involves using the differences in length between branched fibers resulting from construction and end reflections at a common test light cut-off filter [3] installed in front of an optical network unit (ONU) to measure existing optical access networks without any additional optical devices. Two optical pulses are launched into the fiber under test (FUT) with a time difference Δt and an optical frequency difference Δf. The light pulses have lower and higher optical frequencies and are respectively called the probe and pump pulses.

The probe pulse is reflected at the far end, and collides with the pump light at a position corresponding to the time difference Δt, Then a Brillouin interaction occurs. In this Brillouin interaction, the probe pulse is amplified by the pump pulse. The generated Brillouin gain corresponds to the loss experienced by the pump light until the collision position; therefore, Brillouin gain analysis can be used to measure the optical loss. The probe pulse that obtained the Brillouin gain returns to the incident side with a time difference corresponding to the branched optical fiber length difference. Therefore, it is possible to acquire the optical loss data for each branched optical fiber by analyzing the Brillouin gain for each pulse. Note that it is necessary to set the probe pulse so that it is narrower than the time difference caused by the branched optical fiber length difference. In addition, it is possible to acquire the loss distribution data by changing the time difference Δt.

We describe here the remote and single-end measurement of the LIL [5] and connection loss [6] using the branched optical fiber loss measurement technique. The LIL is obtained by subtracting the far-end return loss from the loss that the pulse experienced in the round-trip. The round-trip insertion loss of the probe pulse is measured without a pump pulse. The far-end return loss is obtained with the gain difference given immediately in front of the reflector by

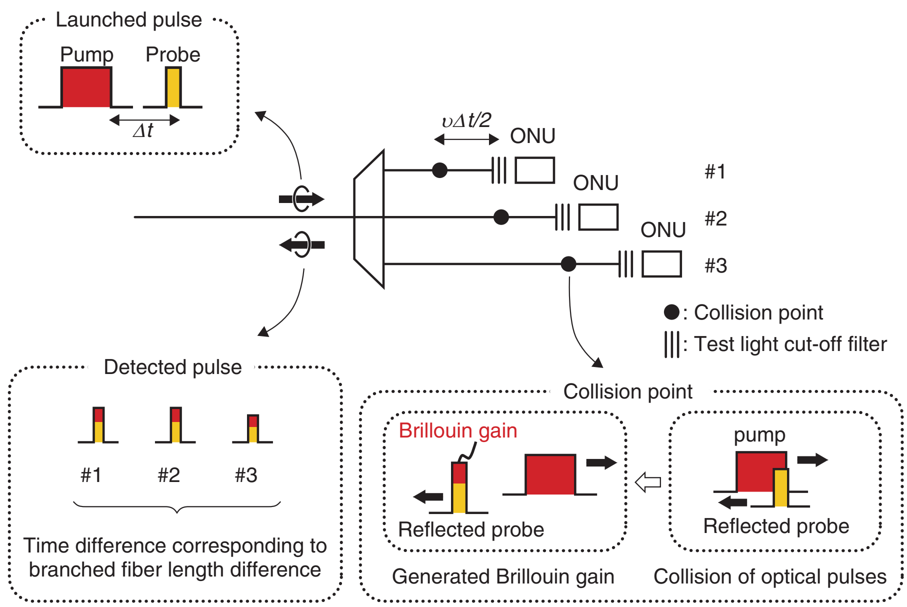


Fig. 2. Schematic diagram of branched optical fiber loss measurement technique.

changing the launch order of the probe and pump pulses. Therefore, this technique can be used to conduct a remote LIL measurement for each customer.

The connection loss can be measured by changing both the time difference Δt and the launch order of the probe/pump pulse. When we launch the pump after the probe, we can obtain the loss distribution from the input end, and when we launch the probe after the pump, we can obtain the pseudo loss distribution from the far end. Therefore, bidirectional measurement can be achieved from a single end.

3. Developed apparatus of branched optical fiber loss measurement

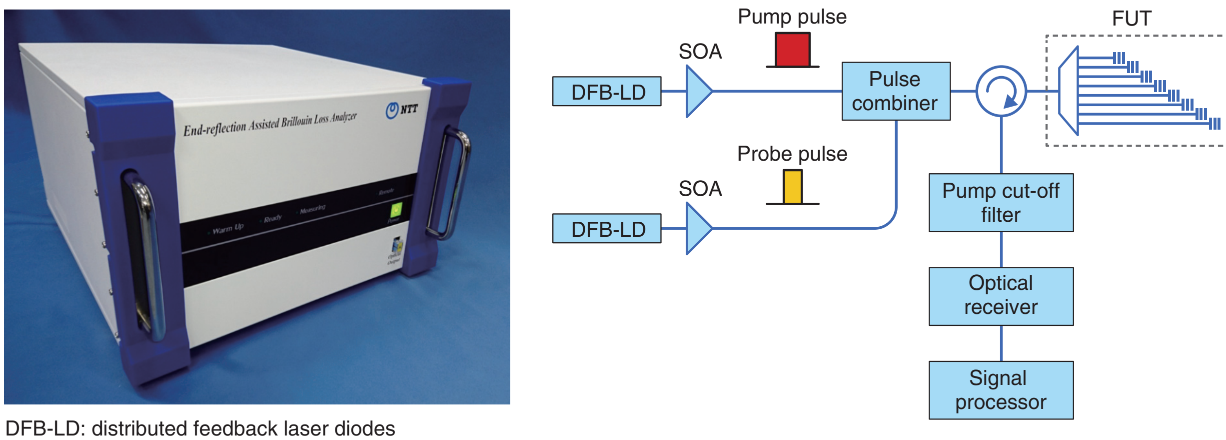
A photograph and the configuration of the measurement system we developed are shown in **Fig. 3**. Two DFB-LDs (distributed feedback laser diodes) were used as probe/pump sources, whose frequency difference was set at a Brillouin frequency shift of about 10 GHz. The probe/pump lights were launched into an FUT after being amplified and pulsed by SOAs (semiconductor optical amplifiers) 1 and 2. The reflected probe pulses from the FUT were detected at the PD (photodetector) after removing the pump light with an optical filter. This is the first technique capable of measuring optical loss using Brillouin phenomena, and it is the only technique that can measure the loss distribution beyond an optical splitter.

4. Measurement examples with branched fiber loss measurement apparatus

In this section, we describe some examples of measurements obtained with our branched fiber loss measurement apparatus.

The measurement results for branched optical fibers obtained with the developed measurement apparatus and conventional LSPM and OTDR are shown in **Fig. 4**. The FUT, which was composed of six fibers of different lengths, is depicted in Fig. 4(a). The LIL results obtained with LSPM and the developed apparatus are in Fig. 4(b). It can be seen that the result with the technique developed for single-end measurement agrees well with the result measured using LSPM. The results obtained with unidirectional OTDR and the developed apparatus are presented in Figs. 4(c) and (d). They show that the loss distribution of branched fiber sections cannot be measured with unidirectional OTDR. In contrast, it can be seen that the developed apparatus can measure individual loss distributions including loss events.

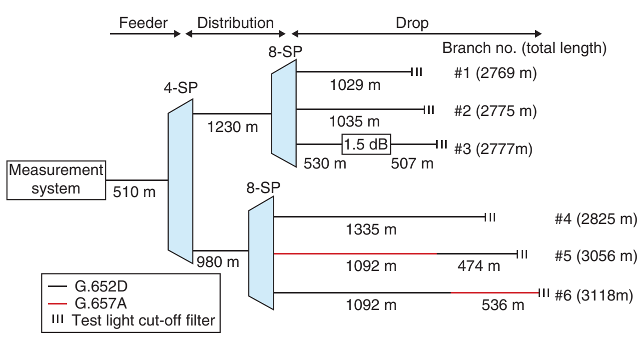
The connection loss results obtained with bidirectional OTDR and the developed apparatus are shown in **Fig. 5**. The FUT was composed of optical fibers with different bending characteristics (G.652D and G.657A). The results obtained with the developed apparatus for single-end measurement agree well with those obtained with bidirectional OTDR.



DFB-LD: distributed feedback laser diodes
SOA: semiconductor optical amplifier

Fig. 3. Measurement apparatus and configuration.

(a) FUT configuration



(b) Example of LIL results

Branch no.	LIL Developed technology* (dB)	LSPM (dB) (comparison)
#1	17.6 ± 0.3	17.9
#2	17.4 ± 0.3	17.7
#3	18.7 ± 0.6	19.2
#4	17.5 ± 0.4	17.8
#5	17.3 ± 0.2	17.9
#6	17.2 ± 0.3	17.1

* Continuously monitored for 2 hours

(c) Example of OTDR result (comparison)

(d) Example of individual loss distribution results

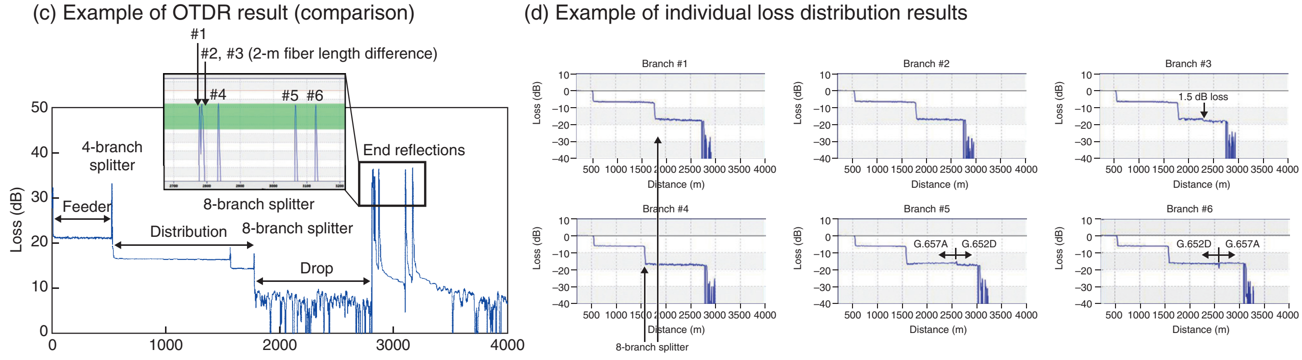


Fig. 4. Examples of LIL and loss distribution in branched optical access network.

5. Field demonstration

The configuration and measurement results for a field demonstration using the developed apparatus are shown in **Fig. 6**. A 4-branch splitter was installed inside a central office, and an 8-branch splitter was installed in a distribution area near four customers' premises. FBG (fiber Bragg grating)-based reflectors

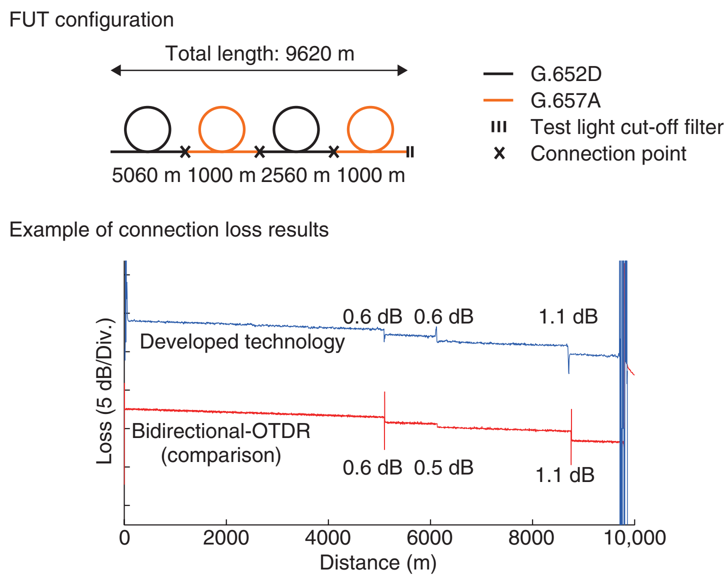


Fig. 5. Example of connection loss measurement results with heterogeneous fiber connection.

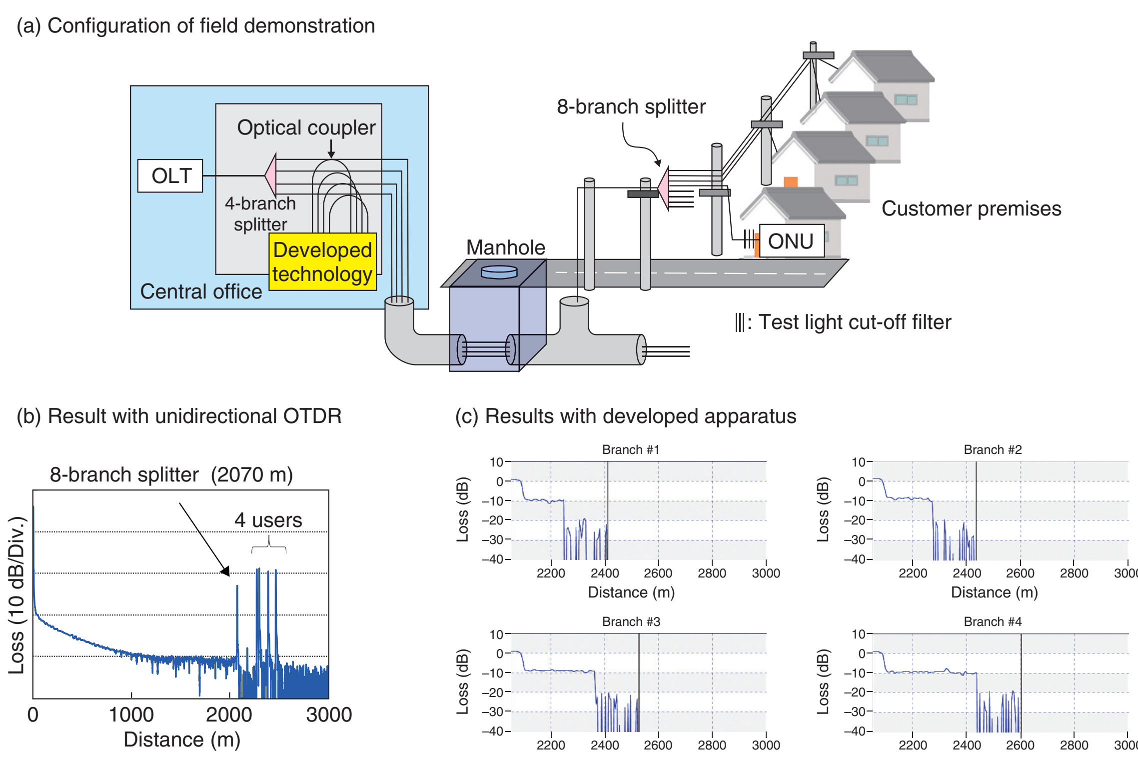


Fig. 6. Field demonstration using developed technique.

with a nominal return loss of 1 dB at 1650 nm were installed just in front of an ONU. The total length of the test optical distribution network (ODN) was about 2.5 km. We performed the measurement from a test coupler installed immediately below the 4-branch splitter.

Measurement results obtained for a deployed ODN with OTDR and the developed apparatus are shown in Figs. 6(b) and (c). The branched fiber sections were successfully visualized with the developed apparatus in the field.

An OTDR trace of the entire ODN is shown in the graph in Fig. 6(b). An 8-branch splitter was installed at 2070 m, and there were four end reflections on the customers' premises. Enlarged traces of the drop fiber section beyond the 8-branch splitter, which were measured with the proposed system, are in Fig. 6(c). The branched fiber sections were successfully visualized. As mentioned above, the developed apparatus can measure the individual loss distribution for each customer even if the OTDR cannot do so because of overlaps from the branched fiber section or because of the excessive loss of the splitter.

6. Future perspectives

We introduced branched optical fiber loss measurement technology that enables end-to-end measurement of optical access networks. Since this technology uses end reflection, there are conditions that cannot be measured depending on the optical access networks, such as when they are completely disconnected, when there is a large loss near the far end, and when there is no branch fiber length difference.

Nevertheless, we believe that a centralized approach, which is a unique and attractive feature of the developed technology, would result in operational applications that overcome the lack of fiber-end accessibility. The developed technology was commercialized in 2017. We now plan to start employing it as a troubleshooting tool where we require a detailed diagnosis of optical access networks.

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Hiroshi Takahashi

Research Engineer, Access Media Project, NTT Access Network Service Systems Laboratories.

He received a B.E. in electrical engineering from Tokyo University of Science in 2008 and an M.E. in electrical engineering and information systems from the University of Tokyo in 2010. He joined NTT Access Network Service Systems Laboratories in 2010. He has been engaged in research on optical reflectometry and optical fiber measurements. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan.

Chihiro Kito

Research Engineer, Access Media Project, NTT Access Network Service Systems Laboratories.

He received a B.E. and M.E. in electrical engineering from Toyota Technological Institute, Aichi, in 2009 and 2011, and a D.E. in electrical engineering from Shimane University in 2017. He joined NTT Access Network Service Systems Laboratories in 2011. He has since been involved in research on optical reflectometry and optical fiber measurements. He is a member of IEICE.

Kunihiro Toge

Senior Research Engineer, Access Media Project, NTT Access Network Service Systems Laboratories.

He received a B.E. and M.E. in mechanical engineering and a D.E. in electrical engineering from Waseda University, Tokyo, in 1999, 2001, and 2007. He joined NTT Access Network Service Systems Laboratories in 2001, where he has been researching optical fiber cable and advanced optical measurements. He is presently a senior research engineer in a research group developing advanced optical measurements for fiber network management and evaluation. He has also been involved in standardization activities in ITU-T Study Group 15 since 2011 and has been serving as Rapporteur of Question 17 (maintenance and operation of optical fibre cable networks) since 2012. He received the best paper award at the 12th OECC/IOOC in 2007. He is a member of IEICE.

Tetsuya Manabe

Senior Research Engineer, Supervisor, Access Media Project, NTT Access Network Service Systems Laboratories.

He received a B.E., M.E., and Ph.D. in mechanical engineering from Osaka University in 1989, 1991, and 1998. He also received an MBA (Advanced) from the University of Western Australia in 2007. He joined NTT Access Network Service Systems Laboratories in 1991. His research interests include learning control, robotics, and mechanical system control. He is currently involved in research to improve the efficiency of telecommunication system maintenance. He is a member of IEICE and the Society of Instrument and Control Engineers.

High Precision 12-single-mode-fiber Multi-fiber Push-on Connector for Reference Use in Connector Evaluation

Ryo Koyama, Chisato Fukai, Yoshiteru Abe, Mitsuru Kihara, and Kazunori Katayama

Abstract

The data transfer speed between data communication equipment in datacenters has been increasing in recent years, and the use of multi-fiber optical links for the communication wiring in such buildings is expanding. In particular, the 12-fiber multi-fiber push-on (MPO) connector for single-mode fiber is expected to be widely used in the future, but an accurate evaluation method is necessary for its proper procurement. We introduce the high precision 12-fiber MPO connector developed as a reference for MPO connector evaluation.

Keywords: multi-fiber optical connector, reference connector, optical connector evaluation

1. Introduction

The data transfer speed between communication equipment has been increasing in communication facilities such as datacenters. Therefore, the use of multi-fiber optical links as opposed to single-fiber optical links is expanding in high speed communication links. Multi-fiber push-on (MPO) connectors, a type of optical connector developed by NTT, are most widely used as the interfaces of multi-fiber optical links in buildings. An example of the standard wiring of a datacenter is shown in **Fig. 1** [1]. In modern datacenters, high speed communication links such as 40 Gbit/s or 100 Gbit/s are widely used between the aggregation switches and spine switches, and their link speed continues to increase. Examples of the standard high speed communication links using the MPO connector are listed in **Table 1** [2–4]. Because inter-switch communication at a datacenter is expected to be over 100 Gbit/s in communication speed and over 100 m in wiring length, the 12-single-mode fiber MPO connector is expected to be used more and more for high-speed communication optical wiring in buildings.

The structure of the MPO connector is shown in **Fig. 2**. The MPO connector consists of a male plug, which contains pre-inserted guide pins, a female plug with guide pin holes on the connector endface, and an adaptor that couples the plugs with a slide lock mechanism. To connect optical fibers, we have to align the positions of the fiber cores through which signal light passes in order to bring the fiber cores in contact with each other. In the MPO connector plug, the fibers are precisely arrayed and fixed into a mechanically transferable (MT) ferrule, and when one plug is connected to another one, the MT ferrule is aligned with the opposite MT ferrule by using the guide pins and the guide pin holes.

In an actual optical connector connection, it is difficult to perfectly match the positions of the fiber cores, and some of the signal light is consequently lost and not transmitted. This loss (connection loss)

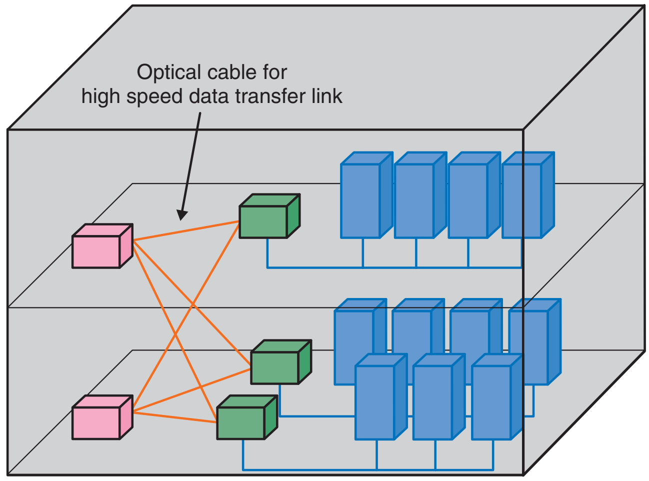
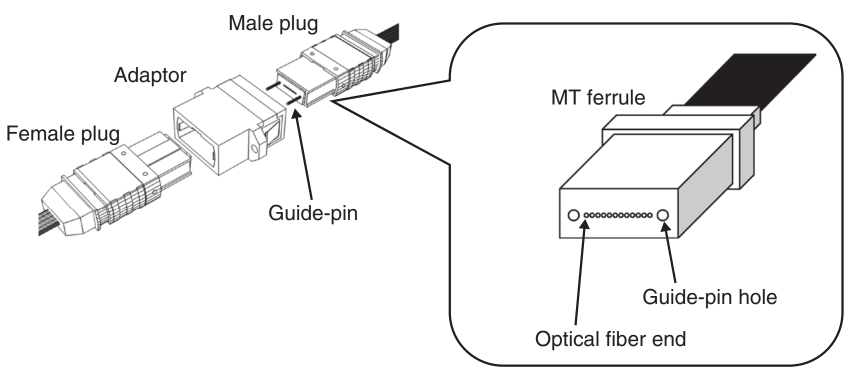


Fig. 1. Example of cabling for datacenter building.

Table 1. Examples of high speed data transfer links using MPO connector interface.

Data transfer speed	Specification name	Optical fiber	Number of fibers	Distance range
40 Gbit/s	40GBASE-SR4	Multi-mode fiber	12	150 m
100 Gbit/s	100GBASE-SR4	Multi-mode fiber	12	150 m
	100GBASE-PSM	Single-mode fiber	12	2 km
200 Gbit/s	200GBASE-SR4	Multi-mode fiber	12	100 m
	200GBASE-DR4	Single-mode fiber	12	500 m
400 Gbit/s	400GBASE-SR16	Multi-mode fiber	32	100 m
	400GBASE-DR4	Single-mode fiber	12	500 m



MT: mechanically transferable

Fig. 2. Structure of MPO connector.

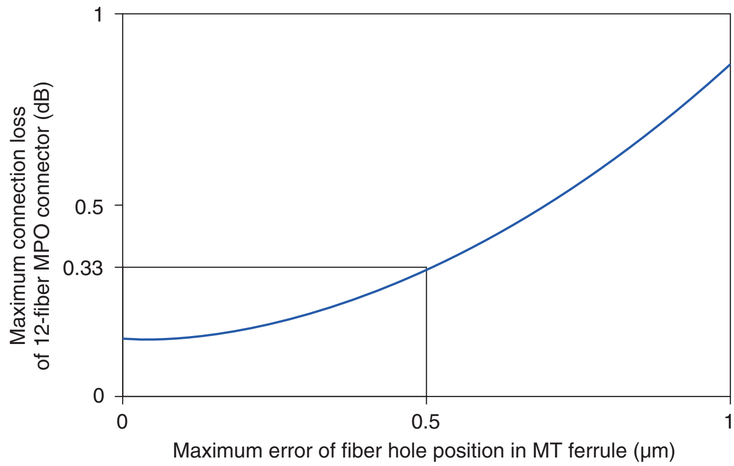


Fig. 3. Calculated connection loss in MPO connector.

affects the communication quality, so it is necessary to evaluate the connection loss. One evaluation method involves using a reference connector. The reference connector should be a highly accurate connector manufactured with less error than the standardized ideal design of an optical connector. This method is widely used because it is accurate based on the standardized design, and it guarantees the interoperability of the optical connectors.

However, there are no reference connectors currently available on the market for the MPO connector, so it is not possible to conduct an accurate evaluation as done for the conventional single-fiber optical connector. Consequently, there may be uncertainty about the measured connection loss between, for example, the manufacturer and the purchaser in the evaluation of the MPO connector. In addition, when the MPO connector is required to have a connection loss equivalent to the conventional single-mode-fiber optical connector, the connection loss of the MPO connector cannot be guaranteed.

We introduce here a high precision 12-single-mode-fiber MPO connector that we developed as a reference connector to achieve accurate evaluation of the 12-single-mode-fiber MPO connector. Our high precision MPO connector is the world's first 12-fiber MPO connector for single-mode fiber that meets the specifications of the International Electrotechnical Commission (IEC) reference connector.

2. High precision MPO connector

In the connection of optical connectors, any positional error of the fiber core will mainly affect the connection loss, so the target position of the fiber core is specified. However, the actual optical connector may have a deviation between the fiber core position and the target position due to a manufacturing error. The reference connector must therefore be a high precision connector with small error of the fiber core position. For example, the IEC specifies that the connection loss between reference connectors shall be no more than 0.2 dB, which means that the error of the fiber core position should be 0.5 μm or less [5].

There are two difficulties in achieving high precision multi-fiber connectors with a connection loss of 0.2 dB or less. One is the effect of manufacturing error. As mentioned above, in the MPO connector, the fiber cores are aligned by the MT ferrule, but the MT ferrule has a manufacturing error of 0.5 μm at maximum.

The connection loss of the MPO connector calculated based on the manufacturing error of the MT ferrule is given in **Fig. 3**. The figure shows that the connection loss of the MPO connector given the maximum 0.5-μm manufacturing error of the MT ferrule exceeds the target loss of 0.2 dB. It is difficult to reduce the manufacturing error to less than 0.5 μm with the current manufacturing technology, so in order to achieve a 12-core high precision connector, it is necessary to select connectors with a small manufacturing error from those manufactured with the maximum error of 0.5 μm.

The other difficulty lies in measuring the error of the fiber core positions in the MPO connector. In the MPO connector, fiber cores with a diameter of about

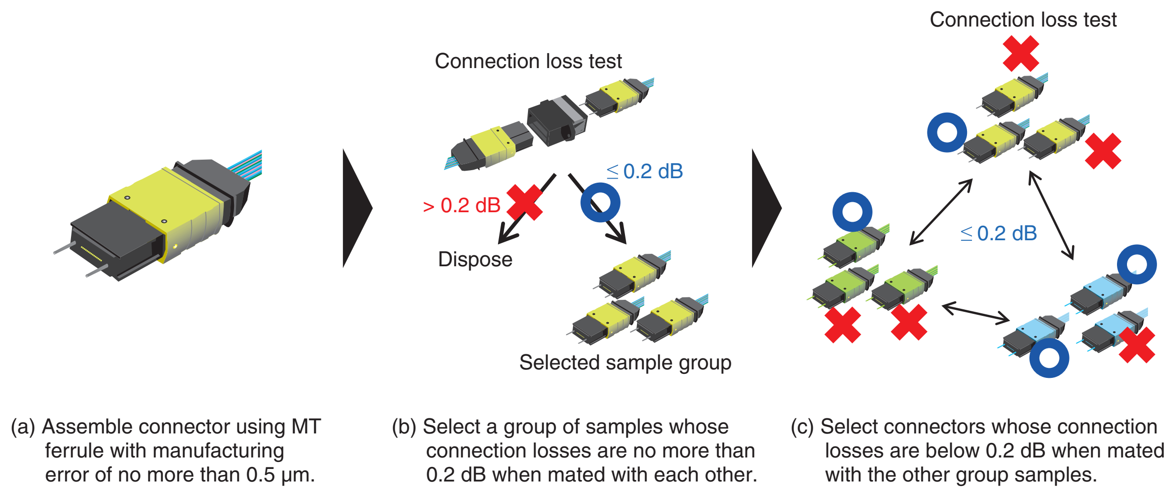


Fig. 4. Selection procedure for high precision MPO connectors.

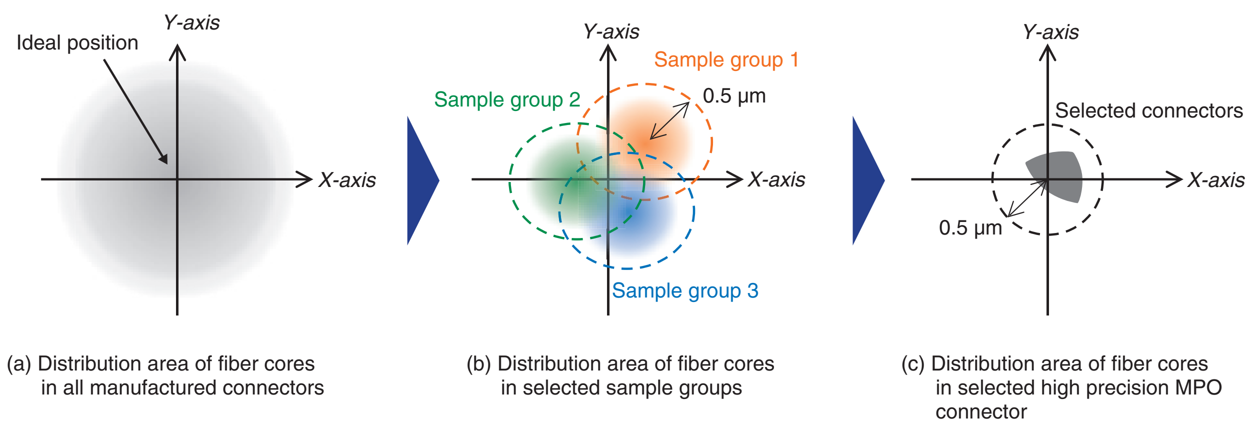


Fig. 5. Example of fiber core position of selected connector samples.

10 μm are lined up in a 4.6-mm-wide area. The fiber core position cannot be measured accurately because of the large difference between the observation range and the size of the fiber core to be measured. For this reason, it is not possible to select connectors with a small manufacturing error based on the fiber core position itself.

The procedure for selecting connectors using connection loss when the actual fiber core position is unknown is shown in **Fig. 4**, and an example of the fiber core position in each procedure is shown in **Fig. 5**.

First, we manufacture an MPO connector using an MT ferrule with a manufacturing error of 0.5 μm or less. The fiber core position of the fabricated connector is distributed around the target position, as shown in Fig. 5(a), due to manufacturing error. Next, as shown in Fig. 4(b), we connect the fabricated MPO connectors together and select a sample group exhibiting a connection loss of 0.2 dB or less. Through selection, connectors whose fiber core position is in the range of 0.5 μm are extracted, although the center of the fiber core position will deviate from the ideal position, as shown in Fig. 5(b).

To select connectors with a fiber core position error of less than 0.5 μm from the ideal position, we prepared three sample groups and selected the connectors that had a connection loss of 0.2 dB when they were connected to the connectors of the other sample group. Although the fiber core position of each

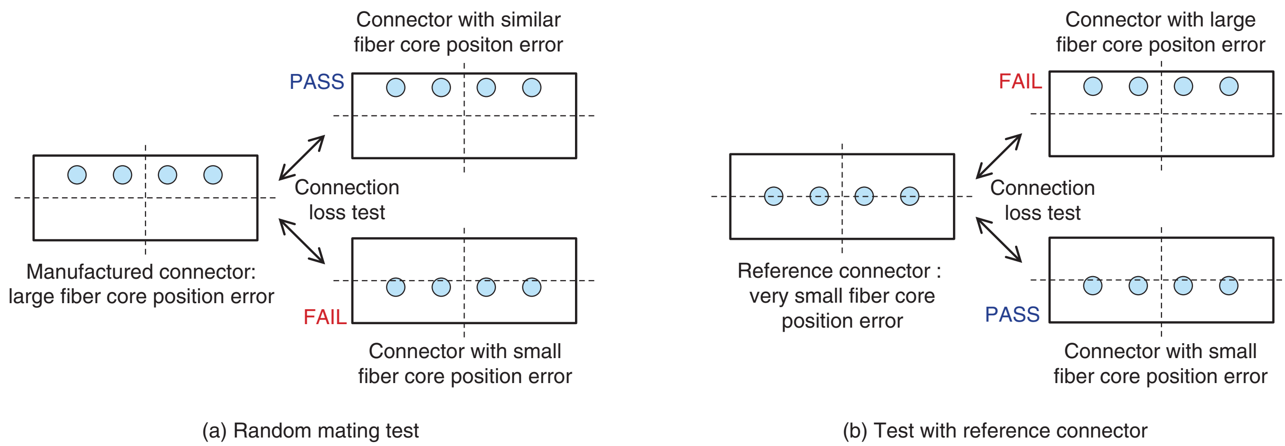


Fig. 6. Example of MPO connector evaluation methods.

Table 2. Reference connectors in major optical connectors.

Connector family	Standard	Requirement for fiber core position error	Requirement for connection loss
SC connectors	JIS C5973	Below 0.5 mm	Below 0.2 dB
MT connectors	JIS C5981	No requirement	Below 0.2 dB
MPO connectors	JIS C5982	No requirement	Below 0.3 dB
Our developed high precision MPO connector	—	Below 0.5 mm	Below 0.2 dB

JIS: Japanese Industrial Standards
SC: subscriber connector

sample group is unknown, the range where the fiber core can exist can be estimated to determine whether it is 0.5 µm or less based on the fiber core position of the connector selected between each of the sample groups, as shown in Fig. 5(c). We are using this procedure to achieve a high precision MPO connector with a fiber core position of 0.5 µm or less for the first time in the world.

3. Application to MPO connector evaluation

Two widely used optical connector evaluation methods are depicted in **Fig. 6**. They are used to evaluate the connection losses and other characteristics of the connector. The random mating test method is used when connecting manufactured connectors to each other (Fig. 6(a)). As shown in the figure, the random mating test is not accurate when the fiber core positions have some deviation. Therefore, even if the connection loss was confirmed to be less than a specified value in the random mating test, the connection loss would not always be less than the specified value in actual equipment.

In the other method, the manufactured connectors are tested against a reference connector (Fig. 6(b)). Because the reference connector has low deviation of the fiber core position, this method can be performed accurately as shown in the figure, and interoperability between connectors is guaranteed.

However, even high precision reference connectors have a small deviation of the fiber core position. A comparison between the specifications of the reference connector in major optical connector standards and the developed high precision MPO connector is given in **Table 2** [5–8]. The developed high precision MPO connector has the same deviation of the fiber core position and connection loss as those of the reference connector for single-mode subscriber connectors (SCs). Since the reference connector for a single-mode SC has been utilized in the practical evaluation of single-mode optical connectors for the last few decades, our developed high precision MPO connector has a sufficiently small deviation for the reference connector for practical connector evaluation.

4. Summary and future work

We introduced our developed 12-single-mode-fiber high precision MPO connector to realize accurate connector evaluation of the 12-fiber MPO connector. The developed high precision MPO connector is the first in the world to meet the specifications of IEC's reference connector as a 12-fiber MPO connector for single-mode fibers. The accurate connector evaluation method enables fair competition among connector manufacturers and contributes to the proper procurement of MPO connectors in the NTT Group. We will continue to research a way to achieve a reference connector with more than 12 fibers by focusing on the technological trends of high speed communication.

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Ryo Koyama

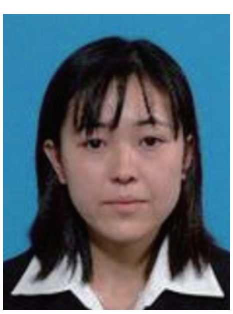
Senior Research Engineer, Media Utilization Group, Access Media Project, NTT Access Network Service Systems Laboratories.

He received a B.S. and M.S. in precision engineering from the University of Tokyo in 2001 and 2003. In 2003, he joined NTT Access Network Service Systems Laboratories, where he has been engaged in research on optical fiber wiring and splicing techniques for optical access networks. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE).

Mitsuru Kihara

Senior Research Engineer, Media Utilization Group, Access Media Project, NTT Access Network Service Systems Laboratories.

He received a B.E. and M.E. in nuclear engineering, and a Dr.Eng. in electronic engineering from Kyushu University, Fukuoka, in 1988, 1990, and 1997. He joined NTT in 1990 and began researching optical fiber interconnection techniques, future network planning, and optical fiber sensing techniques. He is a member of IEICE and the Institute of Electrical and Electronics Engineers (IEEE).



Chisato Fukai

Engineer, Media Utilization Group, Access Media Project, NTT Access Network Service Systems Laboratories.

She received a B.E. and M.E. in functional materials science and a Ph.D. in materials science from Saitama University in 1999, 2001, and 2014. In 2001, she joined NTT Access Network Service Systems Laboratories, where she has been researching optical fiber design and related measurement techniques. She is a member of IEICE.

Kazunori Katayama

Senior Research Engineer, Supervisor and Group Leader of Media Utilization Group, Access Media Project, NTT Access Network Service Systems Laboratories.

He joined NTT Access Network Service Systems Laboratories in 1997, where he engaged in research of home area networks. Since 2007, he has been engaged in research on an intermediate session control server and optical line switching system and optical fiber cable systems. He is a member of IEICE.

Yoshiteru Abe

Senior Research Engineer, Media Utilization Group, Access Media Project, NTT Access Network Service Systems Laboratories.

He received a B.E. in electrical engineering, an M.E. in electronic device engineering, and a Dr. Eng. in electrical engineering from Kyushu University, Fukuoka, in 1996, 1998, and 2005. He joined NTT Opto-electronics Laboratories in 1998. His research interests include optical fiber connectors. He is also acting as Assistant Secretary of SC86B of IEC. He is a member of IEICE.

Report on 21st Global Standards Collaboration (GSC-21)

Hideyuki Iwata

Abstract

The 21st Global Standards Collaboration (GSC-21) was held in Vienna, Austria, on September 26 and 27, 2017. Its purpose is to enable standards developing organizations (SDOs) to share information about the activities of the respective organizations and to accelerate standardization activities by avoiding duplication. Seventy-six delegates from 11 SDOs attended the meeting and discussed two strategic topics: artificial intelligence and smart cities.

Keywords: Global Standards Collaboration, artificial intelligence, smart cities

1. Overview

The 21st Global Standards Collaboration (GSC-21) was held at the European Office of the Institute of Electrical and Electronics Engineers (IEEE) in Vienna, Austria, on September 26 and 27, 2017. The meeting was attended by 76 delegates from 11 standards developing organizations (SDOs): ARIB (Association of Radio Industries and Businesses) of Japan, ATIS (Alliance for Telecommunications Industry Solutions) of the USA, ETSI (European Telecommunications Standards Institute), IEC (International Electrotechnical Commission), IEEE-SA (IEEE Standards Association), ISO (International Organization for Standardization), ITU (International Telecommunication Union), TIA (Telecommunications Industry Association) of the USA, TSDSI (Telecommunications Standards Development Society, India), TTA (Telecommunications Technology Association) of Korea, and TTC (The Telecommunication Technology Committee) of Japan (**Photo 1**). Delegates reported on the latest activities and high-priority standardization issues of the respective organizations and discussed the two strategic topics of artificial intelligence (AI) and smart cities. They also deliberated on WRC (World Radiocommunication Conference)-19 Agenda Item 1.12.

2. Activity progress reports from SDOs

The 11 SDOs reported on their latest activities and high-priority standardization issues. Issues where duplication was found were fifth-generation mobile communications networks (5G), SDN/NFV (software-defined networking and network functions virtualization), Internet of Things (IoT), connected cards, security, open source software, blockchain, AI, and smart cities. The last two issues were strategic topics picked for discussion during this meeting.

3. Discussions on strategic topics

A brief description of each discussion topic is given in this section.

3.1 Communication technologies and artificial intelligence in autonomous systems

IEEE-SA served as the facilitator for discussions on AI, and eight SDOs reported on their activities.

(1) ATIS Initiatives in Support of Artificial Intelligence and Autonomous Systems (ATIS)

ATIS explained its 2017 White Paper on cybersecurity of connected cars. The paper addresses connecting paths via clouds, as well as security requirements. ATIS collaborates with Auto-ISAC (Automotive Information Sharing and Analysis Center).

(2) Overview of Communications Technologies for

Photo 1. Participants of GSC-21.

Autonomous and Connected Vehicles (TTA)

TTA is also applying AI to connected cars. It presented the activities of the 3GPP (3rd Generation Partnership Project) concerning Cellular V2X, in which cars communicate with other vehicles and with road infrastructure devices such as traffic signals and road signs directly rather than via clouds. In the future, this technology will lead to automated driving.

(3) ETSI Issues on Artificial Intelligence (ETSI)

ETSI described the action programs and impacts of introducing AI to various fields: radio access technology; vehicle connectivity; IMT2020; access; x-haul and core network technologies; and network management and control. In February 2017, ETSI ISG-ENI (Industry Specification Group on Experiential Networked Intelligence) began studying applications of AI to network operations, including 5G network operation.

(4) Overview of JTC 1 Activities in the Area of Artificial Intelligence (IEC)

The ISO/IEC Joint Technical Committee 1 (JTC 1) explained the evolution and definition of AI technology. One year ago, JAG (JTC 1 Advisory Group) formed a temporary group named JETI (JTC 1 on Emerging Technology and Innovations). It also called for rapid standardization of AI and autonomous systems (AS) and began studying them in JTC 1/SC 7 (subcommittee 7: software and systems engineering), SC 34 (document description and processing languages), SC 40 (IT (information technology) management and IT governance) and Working Group (WG) 9 (big data).

(5) IEEE-SA Initiatives in Artificial Intelligence and Autonomous Systems (IEEE-SA)

IEEE-SA reported that in 2015 it launched a project called Global Initiatives of Ethical Considerations in Artificial Intelligence and Autonomous Systems, and that it was studying applications of AI and AS based on ethics and policy.

(6) Communications Technology and Artificial Intelligence (ISO)

ISO presented its analysis of opportunities and challenges that exist in applying AI to research and development of aviation/space and defense. It explained issues relating to the application of AI such as data quality (specified in ISO 8000), data collection using IoT technology, and the use of blockchain to ensure data security.

(7) AI for Good Global Summit (ITU)

ITU outlined the “AI for GOOD” Global Summit held in June 2017. It was hosted by ITU and the XPRIZE Foundation and sponsored by 20 United Nations organizations. The summit participants discussed how to develop AI that is secure, ethical, and fair in all social aspects.

(8) Standardization Perspectives for Augmental Robotics (TSDSI)

TSDSI presented the concept, challenges, and standardization issues concerning augmental robotics. It is studying a codec for expressing tactile sense and feeling (IEEE P.1918.1) and time-sensitive networking (IEEE 802.1 WG) targeted at use in security-sensitive businesses. It holds particularly high hopes for application of AI to remote medicine because 60% of the Indian population does not have access to basic medical care.

3.2 Smart cities

(1) ATIS Initiatives in Support of Smart Cities (ATIS)

ATIS published the ATIS Smart Cities Technology Roadmap in May 2017. The roadmap presents issues that ATIS identified in four technical fields: access, platforms, applications, and infrastructure. Issues in the access field include cloud data, context awareness, next-generation position detection, and privacy and security management. Platform issues include AI, machine learning, data collection platforms and data exchange, and augmented reality (AR) platforms. Issues relating to applications include AR/VR (virtual reality) content and content cooperation. Infrastructure issues identified were resilience through distribution, facility management, and emergency responses.

(2) Smart City, Achieving Better Life (CCSA)

CCSA reported on smart city projects implemented by Huawei: public services, including sewage and waste treatment, in Dubai; efficient administration of local government in Guangzhou; remote medicine in Kenya; Wi-Fi service in a stadium in Amsterdam; smart tourism in Dunhuang; and a high-speed Wi-Fi network at Newcastle University, UK.

(3) ETSI Strategy on Smart City Standards (ETSI)

ETSI pointed out that technical studies on smart cities are advancing and that standardization reduces the risks faced by individual cities in selecting the technologies that they need. It presented its smart city initiatives and emphasized the need for understanding context in using data, as well as the importance of security, privacy, and trust.

(4) IEC - Using a Systems Approach to Develop Smart City Standards (IEC)

Since a smart city involves complex, large-scale infrastructure, it is important to ensure interoperability. It is necessary to adopt a systems approach in developing smart city standards. IEC formed IEC SyC (Systems Committee) in 2017 and has been working on standardization of smart energy, active assisted living, and low-voltage direct current for implementing smart cities.

(5) IEEE Smart Cities (IEEE-SA)

Various IEEE standards were discussed. These included standards related to 5G and two smart city-related standards: IEEE802.11ax (high efficiency WLAN (wide local area network)) and IEEE P1931.1 (ROOF: real-time onsite operations facilitation), which is aimed at ensuring IoT interoperability and security in local environments such as houses or other buildings.

(6) ISO Smart and Sustainable Cities Development (ISO)

ISO described standardization activities for ISO/TC 268 (sustainable cities and communities), specifically, a standard concerning city-level issues, and activities for JTC 1 WG11 (information technology for smart cities), specifically, a standard concerning machine-level issues. It also referred to cooperation between SC 41 (IoT) and SC 27 (security).

(7) ITU Smart Sustainable Cities and Communities Initiatives: Towards a Smart Global Vision (ITU)

ITU-T's smart city activities are undertaken by U4SSC (United for Smart Sustainable Cities), in which a number of international organizations are participating. U4SSC studied key performance indicators for using information and communication technology (ICT) to achieve smart sustainability and investigated shared knowledge and future directions.

(8) Building the Smart City Together (TIA)

The collaboration between NIST (National Institute of Standards and Technology) and Cybercity Framework, IES-City Framework, US Ignite (an advanced-wireless nonprofit consortium), and First-Net was reported.

(9) India's SMART Cities Initiative and the Role of Standardization (TSDSI)

Critical urban issues facing India are transportation, energy, and sewage. It was stated that the definition of a smart city is that it is backed by relevant standards, that it is secure, reliable, and harmonized, and that ICT and IoT are essential to its implementation.

(10) Sustainable Development of IoT-Enabled Smart Cities in South Korea (TTA)

TTA learned from failures of its past projects that sustainability and interoperability are important, and it believes that it is necessary to expand the horizontal platform of oneM2M and to ensure interoperability via standard interfaces. TTA's current activities included a certification service for oneM2M specifications and interworking with other platforms such as FIWARE.

4. Future plan

The 22nd meeting will be hosted by ISO/IEC in Switzerland in March 2019.

Trademark notes

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Hideyuki Iwata

Senior Research Engineer, Supervisor, Research and Development Planning Department, NTT.

He received a Ph.D. in electrical engineering from Yamagata University in 2011. From 1993 to 2000, he conducted research on high-density and aerial optical fiber cables at NTT Access Network Service Systems Laboratories. Since 2000, he has been responsible for standardization strategy planning for NTT research and development. He has been a delegate of International Electrotechnical Commission (IEC) SC 86A (optical fiber and cable) since 1998 and of the ITU-T Telecommunication Standardization Advisory Group since 2003. He is a vice-chair of the Expert Group on Bridging the Standardization Gap in the Asia-Pacific Telecommunity Standardization Program Forum. In 2004, he received an award from the IEC Activities Promotion Committee of Japan for his contributions to standardization work in IEC.

External Awards

Chairman's Award

Winner: Kazutaka Hara, Katsuhisa Taguchi, Tomohiro Taniguchi, Susumu Nishihara, Kota Asaka, Ken-Ichi Suzuki, Takeshi Arai, and Akihiro Otaka, NTT Access Network Service Systems Laboratories
Date: July 27, 2017
Organization: The Institute of Electronics, Information and Communication Engineers (IEICE) Technical Committee on Communication Systems

For "Characteristic Analysis of Optical Path Penalty for NG-PON2 Coexisting with Other Systems on Same ODN."
Published as: K. Hara, K. Taguchi, T. Taniguchi, S. Nishihara, K. Asaka, K. Suzuki, T. Arai, and A. Otaka, "Characteristic Analysis of Optical Path Penalty for NG-PON2 Coexisting with Other Systems on Same ODN," IEICE Tech. Rep., Vol. 116, No. 401, CS2016-75, pp. 65–70, Jan. 2017.

Encouraging Award

Winner: Ryota Shiina, Toshihito Fujiwara, Tomohiro Taniguchi, and Tomoki Sugawa, NTT Access Network Service Systems Laboratories
Date: July 27, 2017
Organization: IEICE Technical Committee on Communication Systems

For "Proposal of The Optical Video Distribution System Using Digitized-Radio-over-Fiber Transmission."

As a wired rebroadcasting service, the RF (radio frequency) transmission system with HFC (hybrid fiber coaxial) or FTTH (fiber-to-the-home) has been widely used to transmit broadcasting signals via DTT (digital terrestrial television) broadcasting, BS (broadcasting satellite), and CS (communications satellite). Since the RF system conveys the broadcasting signals without any changes for modulation or signals, it enables customers to utilize existing coaxial cables which are used commonly in the customer premises environment. In addition, existing TV (television) sets are utilized as a receiver without an STB (set-top box). However, the RF transmission system has some problems such as an increase in CAPEX/OPEX due to the limitation of transmission distance and branches, since the system needs a dedicated network constructed only for analog transmission.

In this paper, we propose a novel digital video transmission system using DRoF (digitized radio over fiber) technology, which realizes the digital transmission of the RF-based broadcasting signals while retaining the existing input/output interface of the RF signals to/from the transmission network. This system also enables RF-based broadcasting signals to overlay on the exiting digital communication system by sharing the network equipment. We also indicate the transmission rate calculated by an analytical model for the proposed system.
Published as: R. Shiina, T. Fujiwara, T. Taniguchi, and T. Sugawa, "Proposal of The Optical Video Distribution System Using Digitized-Radio-over-Fiber Transmission," IEICE Tech. Rep., Vol. 116, No. 346, CS2016-52, pp. 39–43, Dec. 2016.

FIT Best Paper Award

Winner: Naoko Kosaka, Akira Koyama, Tsuneko Kura, and Koji Kishi, NTT Secure Platform Laboratories; Tadayoshi Maruyama and Koichi Takamatsu, 2017 Sapporo Asian Winter Games Organizing Committee
Date: December 1, 2017
Organization: Steering Committee of the 16th Forum on Information Technology (FIT2017)

For "Applicability Assessment of Integrated Emergency Management Support System, "KADAN" - Using for Management of Large-scale International Sports Tournaments -."
Published as: N. Kosaka, A. Koyama, T. Kura, K. Kishi, T. Maruyama, and K. Takamatsu, "Applicability Assessment of Integrated Emergency Management Support System, "KADAN" - Using for Management of Large-scale International Sports Tournaments -," Proc. of FIT2017, CO-010, Tokyo, Japan, Sept. 2017 (in Japanese).

Best Paper Award

Winner: Mehrdad Kiamari, University of Southern California; Chenwei Wang, DOCOMO Innovations, Inc.; Salman Avestimehr, University of Southern California
Date: December 8, 2017
Organization: The Institute of Electrical and Electronics Engineers (IEEE) Global Communications Conference (GLOBECOM) 2017

For "On Heterogeneous Coded Distributed Computing."

We consider the recently proposed Coded Distributed Computing (CDC) framework that leverages carefully designed redundant computations to enable coding opportunities that substantially reduce the communication load of distributed computing. We generalize this framework to heterogeneous systems where different nodes in the computing cluster can have different storage (or processing) capabilities. We provide the information-theoretically optimal data set placement and coded data shuffling scheme that minimizes the communication load in a cluster with 3 nodes. For clusters with $K > 3$ nodes, we provide an algorithm description to generalize our coding ideas to larger networks.
Published as: M. Kiamari, C. Wang, and S. Avestimehr, "On Heterogeneous Coded Distributed Computing," Proc. of IEEE GLOBECOM 2017, Singapore, Dec. 2017.

IEEE Fellow

Winner: Akira Fujiwara, NTT Basic Research Laboratories
Date: January 1, 2018
Organization: IEEE

For contributions to silicon single-electron devices.

Best Paper Award

Winner: Shun Tobiyama, Yukiko Yamaguchi, Hirokazu Hasegawa, and Hajime Shimada, Nagoya University; Mitsuaki Akiyama and Takeshi Yagi, NTT Secure Platform Laboratories
Date: January 10, 2018
Organization: The 32nd International Conference on Information Networking (ICOIN 2018)

For "A Method for Estimating Process Maliciousness with Seq2Seq Model."
Published as: S. Tobiyama, Y. Yamaguchi, H. Hasegawa, H. Shimada, M. Akiyama, and T. Yagi, "A Method for Estimating Process Maliciousness with Seq2Seq Model," Proc. of ICOIN 2018, pp. 255–260, Chiang Mai, Thailand, Jan. 2018.

Papers Published in Technical Journals and Conference Proceedings

Parsing Expression Grammars with Unordered Choices

N. Chida and K. Kuramitsu

Journal of Information Processing, Vol. 25, pp. 975–982, December 2017.

Parsing expression grammars (PEGs) were formalized by Ford in 2004, and have several pragmatic operators (such as ordered choice and unlimited lookahead) for better expressing modern programming language syntax. In addition, PEGs can be parsed in a linear time by using recursive-descent parsing and memorization. In this way, PEGs have a lot of positive aspects. On the other hand, it is known that ordered choices defy intuition. They may cause bugs. This is due to a priority of an ordered choice. To avoid this, unordered choices are required. In this paper, we define a parsing expression grammar with unordered choices (PEGwUC), an extension of a PEG with unordered choices. By the extension, it is expected that a PEGwUC includes both a PEG and a context-free grammar (CFG), and this allows us to write a grammar more intuitively. Furthermore, we show an algorithm for parsing a PEGwUC. The algorithm runs in a linear time when a PEGwUC does not include unordered choice and in a cubic time in worst-case running time.

Auditory Surprise Model Based on Pattern Retrieval from the Past Observation

M. Yoneya, H.-I. Liao, S. Furukawa, and M. Kashino

Neuroscience, January 2018.

The sensory cortex may adapt to predictable events, focusing instead on unexpected events or surprise stimuli. Previous studies modeled the auditory surprise using the joint probability of an incoming stimulus and the recent short stimulus history. However, such an approach is not applicable to describe a long-term pattern change in auditory sequences, since the joint probability is incomputable due to data sparsity when the window size of the stimulus history increases. Additionally, ‘‘predictive uncertainty” should be considered to prevent overestimation of surprise, since a violation of expectation would not evoke a large surprise when the prediction is made with a sparse observation. Here, we propose a novel auditory surprise model that can detect a deviant sound embedded in long-term pattern changes. Instead of calculating the joint probability, our model uses the similarity-based pattern retrieval from past observation to predict the future behavior of auditory sequences. The predictive uncertainty was expressed as the variance of the prediction distribution, which is inversely correlated with the similarity between the selected past patterns and the recent history. Our model is applicable to any auditory input since it requires neither exact pattern matching nor any conversion of auditory signals into symbolic forms. We conducted two experiments to test the applicability of our model. In experiment 1, we showed that the model could predict the reaction time for detecting the disappearance of tone pips. In experiment 2, we showed that the model could predict a pupil size change after the pattern transition in auditory sequences.
